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ON CONTACT PHENOMENA BETWEEN GNEISS AND LIMESTONE IN WESTERN MASSACHUSETTS

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INTRODUCTION

The eastern part of Berkshire County in western Massachusetts is underlain by a vast area of granitic gneiss, known as the *Becket granite gneiss*.[1]

[1] B. K. Emerson, "Geology of Massachusetts and Rhode Island," *U.S. Geol. Surv., Bull. 597* (1917).

In older papers by the same author, "Geology of Old Hampshire County, Mass.," *U.S. Geol. Surv., Mon. 29* (1898), and "The Geology of Eastern Berkshire County, Mass.," *U.S. Geol. Surv., Bull. 159* (1899), this granite gneiss is designated in part as "Becket conglomerate gneiss" and in part as "Tyringham gneiss."

This gneiss has been regarded as of pre-Cambrian age and the Cambrian and Ordovician rocks that bound it on the west and the east have been thought to lie unconformably upon it.

On its western side, in the Housatonic Valley, the main rock is limestone, called *Stockbridge limestone*, interbedded with quartzite and slate, while on the eastern side there is an area of highly metamorphic schists.

Within the area of the Becket gneiss there are several vertical layers (up to six hundred feet broad) of limestone, which is older than the gneiss. The most important of them, according to Emerson, are situated at Coles Brook in Middlefield, north of Becket Station in Becket, in Washington and Peru, in Hinsdale, and in the valleys of East Lee, Tyringham, and Otis. All the limestone formations within the Becket gneiss area are called *Coles Brook limestone* from the type occurrence at Coles Brook in the northeastern part of the mass. A striking topographical feature of these occurrences of limestone is that they occupy long, narrow valleys in the gneiss highland.

Near the contacts with this limestone the Becket gneiss shows two kinds of endomorphic contact phenomena: In many cases the boundary type of gneiss grows more basic and is called *Lee quartz diorite*. But in other places, the boundary type of gneiss is rich in salic minerals and contains monoclinic pyroxene and titanite. It is called by Emerson "*titanite-diopside diorite aplite*," and is supposed by him to represent a product of assimilation of the limestone by an igneous magma.

During a trip to western Massachusetts in July, 1921, the present writer, together with Dr. N. L. Bowen, had the opportunity of studying outcrops and collecting samples of these contact rocks around Benson Pond east of Washington Station, on the railroad line between Washington and Becket stations, north of Becket Station and in the valley of Goose Pond Brook near East Lee.

As the problem concerning the assimilation of limestone by igneous magmas is now being much discussed, this very instructive case may be of some interest to petrologists. A brief note of field observations and of a microscopic study of the materials collected is therefore given in the present paper together with a discussion of the results.

Numerous questions as to why and how the contact rocks have obtained their present characters arise from such studies, but to many of them no definite answers are yet possible. It often seems wiser to direct our efforts toward finding a sound form of the question, according to Bacon's advice: "Bene interrogatum quasi dimidium responsi." These questions, one may hope, will be cleared up either by future experimental investigation or by accumulating more evidence from natural rocks.

The questions to be discussed in the present paper are: Why is limestone sometimes assimilated by magmas, and sometimes not? What are the factors controlling the formation of silicate minerals in limestone during metamorphism? What laws control the distribution of elements, such as Mg and Fe, which replace each other in solid solutions, among different mineral groups, pyroxenes, amphiboles, and micas, in silicate rocks?

I wish to express my best thanks to Dr. N. L. Bowen for pleasant companionship during the excursions and for many discussions, and especially for his trouble in making the necessary grammatical corrections in my writing.

This work has been carried out with pecuniary assistance from the Geophysical Laboratory of the Carnegie Institution of Washington and from two funds for the advancement of scientific research in my native country, Finland, namely, Alfred Kordelin's General Trust for the Advancement of Progress and Knowledge, and Herman Rosenberg's Travelling Bursaries Trust of the University of Helsingfors.

BECKET GRANITE GNEISS

Emerson[1] gives the following description of the Becket granite gneiss:

> It is a medium to fine grained light-colored biotite (or biotite-muscovite) microcline-oligoclase gneiss, with microscopic epidote uniformly blended with the scanty biotite, and the microcline grains commonly grouped as if made of the crushed fragments of larger porphyritic crystals. There are small areas of light-colored porphyritic granite from which the prevalent rock could have been produced by crushing. A micrographic texture is common. Over large

[1] *U.S. Geol. Surv., Bull. 597*, p. 154.

areas the dark constituent is in whole or part magnetite in small octahedra. . . . . At its contact with the graphitic rocks the rock is commonly graphitic, and against the limestone it contains in many places secondary calcite grains and tremolite or actinolite.

The following chemical analyses of the Becket gneiss and a related gneiss have been published:[1]

I. Gneissoid granite, Alderman's quarry, Becket, Toscanose-lassenose. Analysis by G. Steiger. Specimen in Petrographic Reference Collection of U.S.G.S. No. 1649.

II. Granite gneiss, Hoosac Mountain. Toscanose. Analysis by E. T. Allen. Specimen *P.R.C.* 1718. Collected by J. E. Wolff. Consists of quartz, microcline, albite, muscovite, biotite, magnetite, titanite, epidote, apatite, zircon.

III. Composite sample of Becket gneiss from 33 localities in the Sheffield quadrangle. Collected by Joseph Barrell and analyzed by R. C. Wells.

	I	II	III
SiO_2	70.62	67.12	68.56
Al_2O_3	15.31	14.97	14.53
Fe_2O_3	1.06	2.61	1.41
FeO	0.43	2.19	2.91
MgO	0.29	0.54	0.60
CaO	1.30	1.69	2.69
Na_2O	4.55	3.92	3.58
K_2O	4.01	5.15	3.62
H_2O-	0.16	0.19	0.06
H_2O+	0.72	1.13	0.97
TiO_2	0.29	0.37	0.55
CO_2	0.88	....	trace
P_2O_5	0.07	0.14	0.17 ZrO_2 0.02
MnO	.....	0.02	0.03 S 0.03
BaO	.....	0.19 ZrO_2 0.03	0.07 F 0.02
	99.69	100.26	99.82

Through the courtesy of Dr. E. S. Larsen of the United States Geological Survey, I had the opportunity of studying the original specimen of Analysis I, the Becket gneiss from Alderman's quarry. It is a light gray granite, rich in muscovite. All its minerals are clear and unaltered.

In the plagioclase were determined $\beta_D = 1.5345 \pm 0.001$; $\alpha'_D = 1.532 \pm 0.002$; $\gamma'_D = 1.540 \pm 0.002$,[2] corresponding to Ab_{92}.

[1] F. W. Clarke, *U.S. Geol. Surv., Bull. 591*, pp. 33–34.

[2] The composition of the plagioclases, in this study, was ascertained mainly from the indices of refraction determined in rock powder by the immersion method, using

The *microcline* is finely cross-hatched. The feldspars and the *quartz* form the aplitic mass in which scales of *muscovite*, *biotite*, and *calcite* are scattered.

In the muscovite, $\beta_D = 1.615 \pm 0.003$, and in the biotite $\beta_D = \gamma_D = 1.650 \pm 0.003$. Unfortunately there are not yet sufficient data to establish the composition of the micas from the refractive indices. The biotite probably has about 80 per cent of the iron compound.[1]

The mode of this rock was calculated with the following result:

Quartz	27.7	Biotite	4.0
Albite	38.2	Calcite	2.0
Anorthite	3.2	Apatite	0.2
Microcline	15.0		
Muscovite	10.0		100.3

This is a rock in which calcite occurs as a primary mineral. Emerson remarks (*op. cit.*, p. 153): "Because of its proximity to the Coles Brook limestone it contains microscopic grains of calcite."

All the analyses of the Becket gneiss show an ordinary granitic composition with about equal amounts of potash and soda and very little lime. A study of thin sections of a number of specimens proved this to be a general rule. Some of them, however, do not contain any potash feldspar, but all are rich in mica.

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a monochromatic illuminator and Dr. Merwin's dispersion diagram for the set of liquids (see E. Posnjak and H. E. Merwin, *Jour. Amer. Chem. Soc.*, Oct., 1922). In the case of feldspars, where birefringence is low and dispersion sufficiently known, this method offers the advantage that all the indices of refraction can be determined with only one liquid. In the actual work it was found convenient either to determine β only, or to seek grains showing the highest birefringence and determine, in three of four grains, α' and γ', taking the lowest and highest values found. The composition was then located on the curves published by F. E. Wright, *Am. Jour. Sci.* (4) (1913), pp. 36, 540. The latter is the quickest way and sufficiently accurate to give the composition of the plagioclase within the limits of 2 or 3 mol. per cent.

[1] The lowest indices of refraction in biotites recorded are those in yellowish brown biotite from Vesuvius, $\alpha_D = 1.5412$; $\gamma_D = 1.5745$, and the highest those in black biotite from Somma: $\alpha_D = 1.5795$; $\gamma_D = 1.638(3)$. The highest value of γ is much lower than that often found during this work. The maximum value, found in a biotite from biotite gneiss, railroad line between Becket and Washington, was $\gamma_D = 1.660 \pm 0.003$. Taking this value and $\gamma_D = 1.574$ as limits a very rough approximate estimation of the composition of biotites may be obtained graphically.

LIMESTONE AND SKARN[1]

Emerson characterizes the Coles Brook limestone in the following words:[2] "The Coles Brook is a coarse, highly crystalline, magnesian limestone, locally white and pure, generally graphitic and greatly changed to a mass of silicates—chondrodite, wollastonite,[3] wernerite, hypersthene, pyroxene, amphibole, titanite, adularia, pericline, and others. . . . ."

In the following are given the writer's observations on the limestones in western Massachusetts.

About ½ mile east of *Benson Pond*, 1 mile east of Washington Station, a band of limestone, a few meters broad, occurs in the gneiss. It is rendered impure by the presence of greenish white mica, reddish brown chondrodite, and clear brown titanite.

The *mica* is nearly, though not quite, uniaxial and has $\beta_D = \gamma_D = 1.576 \pm 0.002$. It is a magnesian mica, very poor in iron, but probably not phlogopite.

The *chondrodite* is notably pleochroic, α and β reddish brown, γ pale brown. $\dot{a} \wedge \beta = 31° \cdot \alpha_D = 1.621 \pm 0.003$; $\beta_D = 1.632 \pm 0.001$; $\gamma_D = 1.655 \pm 0.003$.

This limestone is a calcite rock and contains no dolomite.

In apparent connection with the limestone, on its continuation along the strike, were found many inclusions of clinopyroxene skarn in an aplitic variety of the gneiss which contains varying amounts of the same kind of pyroxene (Fig. 1) as the skarn.

Many of the inclusions are sharply defined, coarsely crystalline masses of grayish green clinopyroxene, although narrow veinlets always protrude into them from the aplite. These veinlets always contain minute grains of red *grossularite-andradite* which is also concentrated within a narrow zone around the inclusions. It is appar-

[1] "Skarn.—An old Swedish mining term for the silicate gangue (amphibole, pyroxene, garnet, etc.) of certain iron ore and sulphide deposits of Archaean age, particularly those which have replaced limestone and dolomite. The term is used in this sense by Fennoscandian geologists, but it has been extended to cover analogous products of contact metamorphism in younger formations." A. Holmes, *The Nomenclature of Petrology* (London, 1920), p. 211.

[2] B. K. Emerson, *U.S. Geol. Surv., Bull. 597*, p. 21.

[3] This statement about wollastonite does not occur in the other more detailed reports and may be erroneous.

ently heterogeneous, its index of refraction (n_D) varying from 1.775± 0.005 to 1.801±0.005. This means a variation in composition from 25 to 43 wt. per cent andradite in the mixcrystals, supposing them to contain only andradite and grossularite.[1]

The *clinopyroxene* has $\beta_D = 1.696 \pm 0.001$ and the angle $c \wedge \gamma = 43°$. Hence its composition should be $Di_{69}He_{31}$.[2]

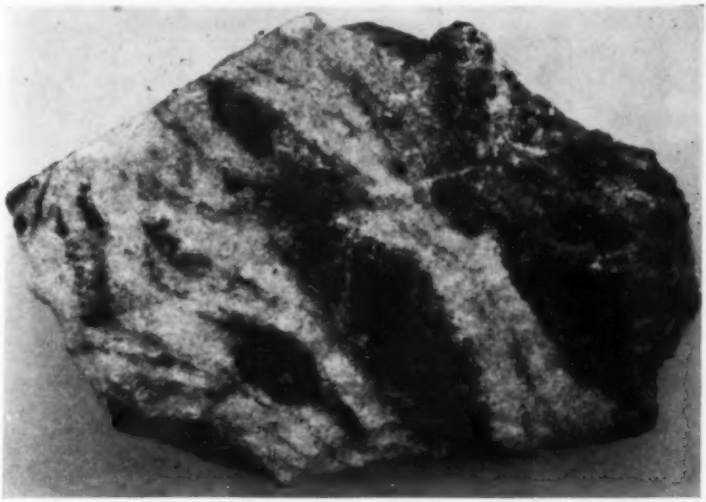

FIG. 1.—Inclusions of clinopyroxene skarn in aplitic gneiss. E. of Benson Pond, Washington, Massachusetts. Eight-ninths natural size.

Together with the garnet in the veinlets there is *quartz*, *microcline* and *plagioclase*. The latter, having $\alpha'_D = 1.532$ and $\gamma'_D = 1.540$, has the composition about Ab_{91}.

[1] W. E. Ford, *Amer. Jour. Sci.* (4), Vol. XL (1915), pp. 33–49.

[2] The determinations of pyroxenes of the diopside-hedenbergite series by means of the indices of refraction were made with a diagram (Fig. 2) based on the optical data given by Wülfing (H. Rosenbusch and E. A. Wülfing, *Mikroskopische Physiographie*, I, 2, p. 203) and on the analyses of the same pyroxenes published by G. Flink (*Zs. Kr.*, Vol. II (1895), p. 585). Although the analyses are antiquated, these data no doubt give a correct idea of the relations between composition and optical properties of clinopyroxenes containing little or no sesquioxydes. Drs. H. E. Merwin and H. S. Washington are at present carrying on an investigation of all the pyroxenes and they no doubt will give a better diagram of this series. As their work is not far advanced and it may be some years before their results are published, we give here the diagram based on Flink's and Wülfing's data.

Small amounts of deep green *hornblende* ($\beta_D = 1.677 \pm 0.002$) are associated with the pyroxene.

Considerable quantities of *epidote* occur near the margins of the skarn inclusions. Its refringence varies within single grains, being lowest in the centers.

On the hillside just *north of Becket Station* there is exposed a vertical layer of limestone, surrounded by clinopyroxene gneiss.

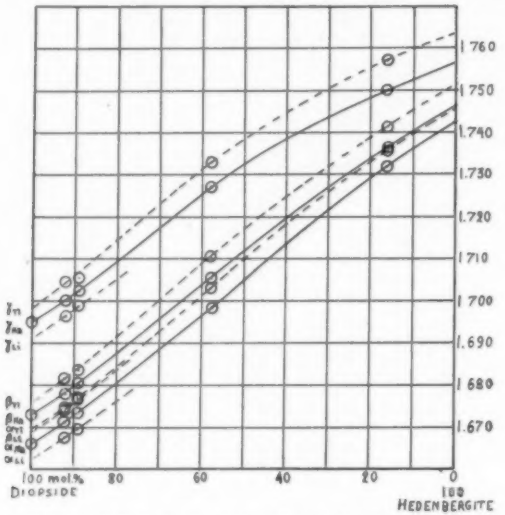

FIG. 2.—Variation of the indices of refraction in the diopside-hedenbergite series. The small amounts of ferric oxide present have been calculated as ferrous oxide. After E. A. Wülfing and G. Flink. The indices of pure diopside were determined by H. E. Merwin.

A specimen of the limestone was found to contain, besides calcite, much quartz and clinopyroxene of the composition $Di_{67}He_{33}$, having $\beta_D = 1.698 \pm 0.002$.

One of those narrow valleys within the Becket gneiss area that are underlain by the Coles Brook limestone is *Goose Pond Brook Valley*. It joins the broader East Lee Valley near East Lee. Limestone occurs in small outcrops in the bed of the brook, and little can be said about its mode of occurrence, but it seems to be in immediate contact with the clinopyroxene gneiss that is exposed close by.

Among the specimens collected some were very rich in *calcite* with only sparing amounts of *dolomite* crystals, the latter being easily recognizable from their higher indices of refraction ($\omega_D = 1.683 - 1.684$; the calcite always was found to have $\omega_D = 1.660$).

Other specimens collected contain pale brown *biotite*, having $\beta_D = \gamma_D = 1.599 - 1.600$, and *quartz*, as rounded grains.

A specimen from the wider *East Lee Valley*, where the Coles Brook limestone occurs as a larger mass, represents a dolomite-rock containing rounded grains of *quartz* and *microcline*, and minute crystals of *pyrite* and scales of brownish, nearly uniaxial *mica* with $\beta_D = \gamma_D = 1.599 \pm 0.002$.

It may be mentioned that these characters are the same as those in the most common types of the Stockbridge limestone in the Housatonic Valley. Analyses[1] of the Stockbridge indicate that there are all variations between dolomite-rocks and calcite-rocks represented. We collected specimens of this limestone from Glendale quarry. It is a dolomite-rock, with much fine scaly brownish *mica* ($\beta_D = \gamma_D = 1.584 \pm 0.002$) and brown *tourmaline* ($\omega_D = 1.639 \pm 0.001$).

BANDED GNEISS NEAR THE LIMESTONE AND THE VARIATION OF ITS MINERAL COMPOSITION

The gneiss, near the vertical, or almost vertical, layers of limestone, always shows a banded structure parallel to the strike of the limestone. At the immediate contacts it is clinopyroxene gneiss. Farther away there are various bands, some containing hornblende, and others with almandite, biotite or magnetite as the principal mafic minerals, and among them are bands of the clinopyroxene gneiss also.

The individual bands may be homogeneous or banded in detail (Fig. 3), due to the unequal distribution of the minerals. The breadth of homogeneous bands varies from less than one meter to a hundred meters. Among the pyroxene-bearing bands, however, none was found thicker than some ten meters.

A common feature of all the varieties of gneiss, of widely different mineral composition, is the presence of very albitic plagioclase (mostly about 90 per cent Ab) and epidote whose

[1] B. K. Emerson, *U.S. Geol. Surv., Bull. 159* (1899), pp. 87 and 99.

amount increases with the quantity of the femic compounds, a fact indicating that it is a substitute for anorthite. The epidote occurs as clear, individual crystals, often intergrown with quartz in the myrmekite fashion.

Another feature significant in connection with the conditions of formation of these banded gneisses is the absence of perthitic threads of plagioclase in the microcline, which is clear and finely cross-hatched. The texture, on the whole, is aplitic, and all the main minerals are equally xenomorphic.

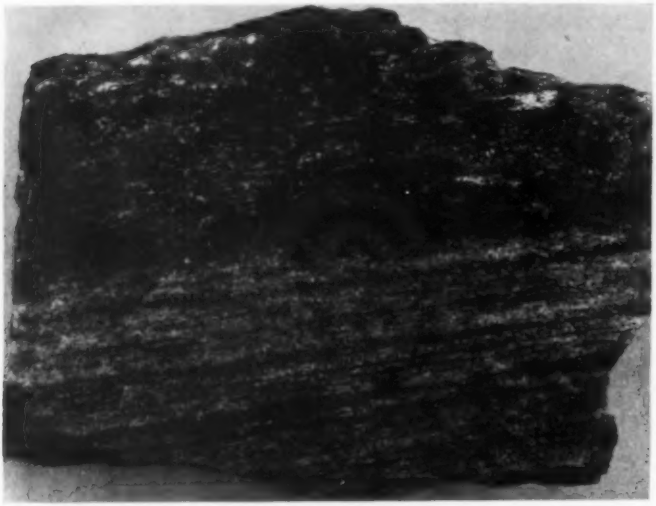

FIG. 3.—Banded clinopyroxene gneiss. W. of Benson Pond, Washington, Massachusetts. Eight-ninths natural size.

Emerson (*op. cit.*, p. 153) published an analysis of clinopyroxene gneiss, called by him "titanite-pyroxene diorite aplite," from "east of C. Conwell's place, South Peru, Mass." The analysis, made by W. T. Schaller, is quoted below (p. 275).

I have found these clinopyroxene-bearing rocks to be exceedingly variable in composition, and the analysis has happened to be made on a rather exceptional type. Most specimens collected by us from the same tract and, also, one collected by Professor Emerson from the Peru line, "the same ledge as the rock analyzed" (*U.S.*

Geol. Surv., P.R.C. 1715), contain considerable amounts of quartz and microcline. They therefore must have a higher percentage of silica and potash. Assuming the plagioclase to contain 90 mol. per cent Ab and a notable quantity of epidote to be present, the mode given in the table was calculated from the rock analysis by the writer. The pyroxene was computed as a diopside-hedenbergite with 10 per cent (Mg, Fe)SiO_3 and 4 per cent Al_2O_3.

The clinopyroxene, in the specimen from the Peru line, is pale green without any notable pleochroism. It was found to have $\alpha_D = 1.695 \pm 0.002$, $\beta_D = 1.706 \pm 0.002$; $\gamma_D = 1.724 \pm 0.002$, and should

	Per Cent	Mol.
SiO_2	60.44	1.007
Al_2O_3	16.26	159
Fe_2O_3	0.07	.....
FeO	3.52	49
MgO	1.75	44
CaO	7.86	140
Na_2O	7.13	115
K_2O	0.44	5
H_2O+	0.38	.....
H_2O-	0.29	.....
TiO_2	1.33	16
P_2O_5	0.58	4
MnO	0.06	1
ZrO_2	0.06	.....
FeS_2	0.10	.....
	100.27	

Mode			
Albite		60.26	
Anorthite		7.51	
Potash feldspar		2.78	
Pyroxene	$CaSiO_3$	8.82	20.49
	$MgSiO_3$	4.40	
	$FeSiO_3$	6.47	
	Al_2O_3	0.80	
Epidote		1.93	
Quartz		2.16	
Titanite		3.14	
Apatite		1.34	
Zircon		0.09	
Pyrite		0.10	
		99.80	

therefore contain 60 mol. per cent diopside and 40 per cent hedenbergite, or $Di_{60}He_{40}$, while calculation from the analysis gave $Di_{48}He_{42}$. Thus the specimen analyzed contained a pyroxene richer in iron. As we shall see, the composition of the clinopyroxene in these gneisses varies markedly from place to place.

The epidote is highly birefracting and has $\beta_D = 1.750 \pm 0.003$, nearly the same value as that found in the epidote from Knappenvand, Sulzbachtal,[1] which contains 33 per cent of the ferric epidote (16 per cent Fe_2O_3) and has $\beta_D = 1.7540$.

[1] M. Goldschlag, *Tscherm. Min. Petr. Mitt.*, Vol. XXXVIII (1917), p. 23. The data given in this study, the most careful one ever carried out on the epidote group, are not yet consistent enough to allow the determination of the amounts of the aluminous and the ferric compounds in epidotes more accurately than with a possible error of ±5 per cent.

The prominent characters of the mineral composition of the various kind of gneiss are stated in the following. The mineral constituents of each rock are named in the approximate order of abundance. The refractive indices were determined, if not stated otherwise, with a maximum error of ±0.003 in biotite and hornblende and epidote, and ±0.002 in plagioclase and pyroxene. The composition of the minerals is given in terms of mol. per cent, stating: in plagioclases the percentage of anorthite (An), in clinopyroxenes (diopside-hedenbergite) the percentage of hedenbergite (He), in hornblende the total Fe as a percentage of Fe+Mg,[1] and in the biotites and epidotes (very roughly) the percentages of their iron compounds.

Aplitic clinopyroxene gneiss around the inclusions of skarn. Mainly microcline, subordinate plagioclase (An_8), quartz, clinopyroxene ($\beta_D = 1.705$, $\gamma_D = 1.727$, He_{42}), epidote, variable, sometimes very poor in Fe,[2] calcite.

Banded clinopyroxene gneiss (Fig. 3) in biotite gneiss, W. of Benson Pond. Microcline, quartz, plagioclase ($\alpha'_D < 1.536$; $\gamma'_D = 1.544$; An_{15}), clinopyroxene (He_{69}),[3] titanite, epidote.

[1] Calculated from the diagrams given by W. E. Ford, *Amer. Jour. Sci.*, Vol. XXXVII (1914), p. 185.

[2] I measured in one case for different wave-lengths, with a maximum error ±0.001:

	α	β	γ
Tl.....	1.703	.....	1.707
D.....	1.698	1.700	1.702
C.....	1.693	.....	1.697

These values are lower than any given in the literature (cf. M. Goldschlag, *loc. cit.*). This mineral is, however, monoclinic, and not a zoisite. $2V = 90°$ appr.

[3] In it were determined, with a maximum error ±0.001:

	α	β	γ
Tl.....	1.724	1.7305	1.748
D.....	1.720	1.726	1.743
C.....	1.716	1.721	1.738

The birefringence suggested that this clinopyroxene is richer in hedenbergite than any other found in this tract. Its refractive indices for various wave-lengths are in fair agreement with those of $Di_{31}He_{69}$ as shown on the diagram. Its extinction

"Pyroxene-titanite aplite" from the Peru line. Plagioclase ($\beta_D = 1.536$; $\alpha'_D = 1.531$; $\gamma'_D = 1.542$; An_{10}), microcline, quartz, hornblende ($\beta_D = 1.676$; Fe_{51}), clinopyroxene ($\alpha_D = 1.695$; $\beta_D = 1.706$; $\gamma_D = 1.724$; He_{40}), titanite, biotite ($\beta_D = \gamma_D = 1.647$; 80 per cent Fe-comp.), epidote ($\beta_D = 1.750$; 33 per cent Fe-comp.), apatite.

Intrusive layer in limestone N. of Becket Station. Quartz, plagioclase (An_{11}), microcline, clinopyroxene ($\beta_D = 1.700$; He_{35}), hornblende ($\beta_D = 1.680$; Fe_{53}), grossularite-andradite ($n_D = 1.80$; 40 wt. per cent andradite), calcite, epidote.

Band in the gneiss, railroad cut W. of Becket Station. Quartz, microcline, clinopyroxene (colorless; $\alpha_D = 1.685$; $\beta_D = 1.690$; $\gamma_D = 1.714$; $\gamma \wedge \dot{c} = 41°$; He_{25}), actinolite (pale green; $\beta_D = 1.638$; Fe_{19}), graphite, calcite, titanite.

Clinopyroxene gneiss near limestone in the valley of Goose Pond Brook. Clinopyroxene (colorless, $\beta_D = 1.681 \pm 0.001$; He_{11}), amphibole ($\beta_D = 1.633 \pm 0.002$; Fe_{14}), quartz, microcline, plagioclase ($\beta_D = 1.534$; An_7), epidote ($\beta_D = 1.730$; 18 per cent Fe-comp. or 9 wt. per cent Fe_2O_3). Occasional scapolite ($\omega_D = 1.572 \pm 0.001$; $\epsilon_D = 1.547 \pm 0.001$; about $Me_{50}Ma_{50}$) and black tourmaline.

Dark band in the gneiss South of Benson Pond. Clinopyroxene ($\beta_D = 1.695$; He_{31}), hornblende ($\alpha_D = 1.672$; $\beta_D = 1.685$; $\gamma_D = 1.695$; Fe_{59}), plagioclase (zoned, An_{17} to An_7), quartz, microcline, titanite, biotite ($\beta_D = \gamma_D = 1.635$; about 65 per cent Fe-comp.).

Dark band N. of Benson Pond. Plagioclase (zoned, An_{23} to An_{16}), hornblende ($\beta_D = 1.660$; Fe_{36}), biotite ($\beta_D = \gamma_D$ 1.642; 75 per cent Fe-comp.), quartz, epidote, titanite, apatite.

Dark band in the gneiss N. of Becket Station. Biotite ($\beta_D = \gamma_D =$ 1.620; 50 per cent Fe-comp.), hornblende ($\beta_D = 1.650$; Fe_{29}), plagioclase ($\beta_D = 1.536$; $\alpha'_D = 1.532$; $\gamma'_D = 1.541$; An_{10}), microcline, quartz, epidote. The quantity of epidote is considerable.

"Lee quartz diorite" from west end of Goose Pond. Plagioclase (zoned, An_{32} to An_{29}), hornblende ($\beta = 1.665$ appr.; Fe_{40}), cum-

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angle $\gamma \wedge \dot{c}$ however, does not accord with the series, being 58° instead of 46° 20′. Probably this clinopyroxene contains a certain amount of aegirite, although its very faint pleochroism (α = pure green, γ = brownish) indicates that the amount may be small.—In another specimen was found a clinopyroxene He_{60}($\beta_D = 1.721$).

mingtonite, forming the inner parts of the aggregates of amphibole (positive, 2V large, $\beta_D = 1.650$; about 40 mol. per cent $FeSiO_3$), quartz, ilmenite, apatite, zircon.

Almandite amphibolite, band in gneiss, roadside W. of Benson Pond. Plagioclase ($\alpha'_D = 1.540$; $\gamma'_D = 1.548$; An_{25}), almandite ($n_D = 1.806 \pm 0.001$; probable composition[1] 70 mol. per cent almandite, 15 mol. per cent pyrope and 15 mol. per cent grossularite), hornblende ($\beta_D = 1.665$; Fe_{40}) microcline, biotite ($\beta = \gamma = 1.648$; about 80 per cent Fe-compound), ilmenite, apatite.

Biotite gneiss, railroad line between Washington and Becket stations. Quartz, plagioclase (An_9) microcline, biotite ($\beta_D = \gamma_D = 1.660$, chiefly iron compound), hornblende ($\alpha_D = 1.697$; $\beta_D = 1.708$; $\gamma_D = 1.709$;[2] $2V\alpha$ small Fe_{90}), magnetite, epidote ($\alpha_D = 1.741 \pm 0.002$; $\beta_D = 1.760 \pm 0.005$; $2V = 75°$ appr.; about 35 mol. per cent iron comp.).

THE MG:FE PROPORTION IN THE VARIOUS BANDS OF THE GNEISS AND IN ITS DIFFERENT MAFIC MINERALS

A comparison of the Fe:Mg proportions, as determined from the refractive indices of the pyroxenes, amphiboles, and biotites in the various kinds of gneiss, shows at once that they are controlled by definite laws. For the sake of convenience, the values of the atomic portions of Fe as a percentage of Fe+Mg (briefly called the Fe-quotient) are tabulated (p. 279).

In this table, the rocks are arranged in the order of decreasing Fe-quotient in their amphiboles and pyroxenes. Now, comparing this order with the statements of the approximate quantitative proportions of the minerals given in the preceding chapter, we find at once that it is, also, at least nearly the order of increasing basicity or decreasing acidity, excepting, however, the two last-named examples of clinopyroxene gneiss. Their case will be discussed below.

[1] P. Eskola, "On the Eclogites of Norway," *Videnskapsselsk. Skri. Mat.-naturv. Kl.* I, No. 8 (1922), p. 9.

[2] The indices match the highest values represented in the amphiboles studied by Ford (*Amer. Jour. Sci.*, Vol. XXXVII [1914], p. 181), i.e., those of the hornblende from Cornwall, Orange County, New York, which has a mean index 1.71 and contains 23.35 per cent FeO and 7.41 per cent Fe_2O_3 against 1.90 per cent MgO and 12.10 per cent Al_2O_3.

In other words: the larger the quantity of the mafic minerals, the smaller is their Fe-quotient. In the most acid types of gneiss, rich in quartz, we find biotite and hornblende, and often clinopyroxene also, extremely rich in iron. In the mafic minerals of the "dark bands" the amount of iron in proportion to magnesia is much less.

At the same time as the Fe-quotient decreases, the amount of anorthite in the plagioclases increases. This relation is somewhat obscured by the epidote, a substitute for the anorthite.

Rocks	100 Fe:(Fe+Mg) in			Other Minerals
	Clinopyroxenes	Hornblendes	Biotites	
Biotite gneiss, railroad at Becket Station	.....	90	95(?)	.....
Clinopyroxene gneiss, W. of Benson Pond	69	.....	.....	.....
Clinopyroxene gneiss, "the Peru line"	40	51	80	.....
Clinopyroxene gneiss, Becket Station	35	53	.....	Grossularite-andradite, 40 per cent andr.
Dark band in gneiss, S. of Benson Pond	31	59	65	.....
Almandite amphibolite, W. of Benson Pond	.....	40	80	Garnet with 70 per cent almandite
Dark band in gneiss, N. of Benson Pond	.....	36	75	.....
Dark band in gneiss, Becket Station	.....	29	50	.....
Clinopyroxene gneiss, railroad between Becket and Washington	25	19	.....	.....
Clinopyroxene gneiss, Goose Pond Brook	11	14	.....	.....

The percentage of the iron compound in the epidotes does not show quite regular relations with that in the mafic minerals. This is probably connected with the later origin of the epidote.

This correspondence between the Fe:Mg ratio and the relative proportion of salic and femic minerals is a special case of what is inherent in any cognate series of igneous rocks which have been derived from a common magma by the processes known as magmatic differentiation. Its occurrence in the banded gneiss proves that the band structure is in itself a product of differentiation. In other words, the "dark bands" are those in which the minerals containing solid solutions are richest in the highest melting compounds or, more exactly, compounds least soluble in the residual magmas. The mafic minerals of these most "basic" members of

the series are pyroxene and amphibole. With increasing acidity biotite and muscovite appear successively.

The occurrence and composition of clinopyroxene does not always follow this rule, and for a very obvious reason: its occurrence is due to the assimilation of limestone, which is dolomitic, and low in iron. Therefore, when it reacts with the highly siliceous gneiss magma, there is formed pyroxene and, also, hornblende and biotite, low in iron, provided differentiation by crystallization has not changed the composition of the magma after assimilation. In many cases a differentiation happened, however, and therefore the mafic minerals of very acid clinopyroxene gneisses not immediately connected with limestone usually show a high Fe-quotient.

Another interesting question is this: How are magnesia and the iron oxides distributed between the different ferromagnesian minerals?

As appears from the table on page 279, there are definite relations between the pyroxenes, amphiboles, and biotites, in this respect. Biotite is regularly the richest in iron and clinopyroxene the poorest. The figures do not show any constant relations between the Fe-quotients, however. This is only what may be expected. From theoretical considerations the distribution of elements in different isomorphous series in a rock is evidently a very complicated process, depending upon the composition of the solutions from which the minerals crystallized and, also, on the temperature and pressure conditions during crystallization. In rocks of identical bulk composition these relations may be expected to vary with the physical conditions. It may be hoped that, when once they are better understood, we shall be able to draw from them certain conclusions as to the conditions under which the rocks originated.

The present writer has formerly studied the almandite-pyrope garnets of different rocks from this standpoint and has arrived at the conclusion that, in rocks of similar composition, those formed under highest pressures have garnets richest in the magnesia compound.[1]

[1] P. Eskola, "The Mineral Facies of Rocks," *Norsk geologisk Tidskrift*, Vol. VI (1920), p. 172.

These brief statements are given here in order to call the petrologist's attention to these relations, formerly very little studied.

VARIATION OF MINERAL PARAGENESIS IN METAMORPHIC LIMESTONE

Sedimentary limestones generally consist of carbonates of calcium and magnesium, and of silica, in the form of quartz. Very often they also bear clayey materials, containing alumina, iron oxides, potash, etc. When such material is brought from surface conditions down to deeper levels where a higher temperature prevails there will occur reactions of the general type:

$$RCO_3+SiO_2=RSiO_3+CO_2.$$

The temperature limit above which the right-hand side of the foregoing equation represents the stable combination, or the transformation point of the chemical system, is raised with pressure. For the reaction $CaCO_3+SiO_2=CaSiO_3+CO_2$, V. M. Goldschmidt calculated the approximate equilibrium curve on the basis of Nernst's affinity theorem.[1] According to this curve, the equilibrium temperature increases rapidly with the pressure, being 850° at 300 atm. Thereafter the rise of the equilibrium temperature with pressure should be nearly linear and so slow that as much as 15,000 atm. would be needed at 950°. Considering rocks of neighboring occurrences which have originated under similar pressures but at different temperatures, as is often the case at the contacts of igneous masses, the limestone indicates what parts of it have been heated above the reaction point. If the pressure be known, the temperature may be estimated in degrees. In the case of rocks whose metamorphism has taken place under pressures of more than 3,000 atm., or at depths of more than 10 kilometers, the equilibrium temperature is but slightly variable with pressure, and the mineral composition of silica-bearing limestones is mainly an indicator of temperature, or the limestone may be used as a *geologic thermometer*.

This curve is not claimed to be more than approximate. Experimental investigation may give considerably different results.

[1] V. M. Goldschmidt, "Die Gesetze der Gesteinsmetamorphose," *Vid. selsk. Skr. Mat.-naturv. Kl.*, No. 22 (1912).

Certain facts known at present would seem to indicate that the curve may lie at somewhat lower temperatures. Its general character, however, agrees well with petrological experience and is not likely to be subject to any great changes.

From the standpoint of the phase-rule, a mixture of calcium carbonate and silica is a three-component system and therefore can have a maximum of three phases in coexistence under variable pressure and temperature conditions, that is, in a divariant system. Below the transformation curve the possible three-phase combinations are either silica, calcite, and carbon dioxide or silica, calcite, and wollastonite. Above the curve we may have either wollastonite, carbon dioxide, and calcite or wollastonite, carbon dioxide, and quartz (or any other form of silica).

Thus wollastonite may be stable and even be formed at temperatures below the transformation curve, but only if silica meets lime in other form than carbonate and no free carbon dioxide is present. The occurrence of wollastonite, therefore, is not in itself a sufficient evidence that the rock had been heated above the transformation temperature. On the other hand the occurrence of both quartz and calcite proves conclusively that it never has.

The temperature of transformation may be considerably depressed if the partial pressure of carbon dioxide is kept low as a result of its continual removal, e.g., by circulating solutions. This case may occur in the formation of metasomatic ore deposits, and in fissure veins. The conditions are here complicated also because the addition of substances and formation of minerals may have continued at different temperatures. As a matter of fact, observation usually indicates a definite sequence of formation of minerals in such deposits.

While, then, many complications are to be expected where circulating solutions have been prominent agents, we may still use limestone as a geologic thermometer with considerable confidence in those cases in which quartz or the silicates occur evenly distributed as true rock constituents.

As we are concerned, in natural rocks, with calcium and magnesium carbonates, the resulting silicates will be those of calcium and magnesium, or double compounds of both. It is to be expected

that magnesium-bearing carbonates will react with the silica at lower temperatures than calcium carbonate. Each silicate to be formed may have its own equilibrium curve.

This assumption has been very strongly supported by petrological investigations which I have carried out in the pre-Cambrian limestone of Finland.[1] In the southeastern part of the pre-Cambrian area of Fennoscandia there are extensive formations all of whose characters point toward metamorphism at low temperatures. In the limestones of this area, quartz occurs together with dolomite, and fine scaly micaceous minerals (biotites rich in magnesia) are usually the only silicates. Sometimes epidote occurs, a fact indicating that this hydrated calcium aluminium silicate also belongs to the low temperature minerals.

Northwest of this low temperature area there is a broad zone within which the limestones contain, besides mica, amphiboles of the tremolite-actinolite series, but no other silicates. Going farther northwest diopside-hedenbergite is added to the list of minerals of the metamorphic limestones, together with many others, such as scapolite, vesuvianite, and grossularite-andradite. Finally we find, as local developments near the contacts of igneous masses, but never in regional distribution, wollastonite limestone, and in this most of the other silicates may occur also. This mode of occurrence clearly indicates that wollastonite, among the lime-bearing silicates, requires the highest temperature to form.

We may thus discriminate the following four paragenetic types of limestones:

1. **Quartz limestone,** in which quartz is coexistent with the dolomite.

2. **Tremolite limestone.** Tremolite is usually present; quartz occurs in calcite-rock, but is not coexistent with dolomite.

3. **Diopside limestone.** Diopside is usually present, quartz occurs together with calcite but not with dolomite.

4. **Wollastonite limestone.** Wollastonite is present, provided the rock contains silica in excess of the amount needed to form the

[1] Pentti Eskola, Victor Hackman, Aarne Laitakari ja W. W. Wilkman, Suomen kalkkikivi. With an English summary by P. E., "Limestones in Finland," *Suomen Geologinen Toimisto, Geoteknisiä Tiedonantoja*, No. 21 (1919).

magnesium-bearing silicates. Quartz and calcite do not occur in contact with each other. Instead either of the combinations calcite-wollastonite or wollastonite-quartz occurs.

Actual rocks have commonly been found in fair accordance with these rules of association. As was pointed out above, wollastonite is in itself stable below the transformation temperature of calcite-silica, if there is no free carbon dioxide present. In the same way diopside and tremolite are stable below those temperatures where they may be formed from the carbonates and silica, again provided that there is no carbon dioxide present. Now there actually is no free carbon dioxide after the formation of the silicates, as it is carried away either as gas or in solutions. Therefore, although the reactions are reversible, they are not reversed during the period of gradual cooling when the rocks are brought up toward the earth's surface through the process of denudation. This fact, of course, adds very much to the usefulness of metamorphic limestone as a geologic thermometer. We always read the highest temperature to which it has ever been exposed. It is a maximum thermometer.

The formation of different minerals under different conditions in limestones presents a special case of the more general rules of adjustment of mineral composition in response to the conditions existing. The writer has proposed the term *mineral facies*[1] to designate a group of rocks which have originated under conditions so similar that a definite chemical composition has resulted in the same set of minerals. Applying this principle to various kinds of rocks, we arrive at a natural rock classification in which main divisions are the groups called mineral facies.

The four paragenetic types of limestone may be paralleled with the facies system of the silicate rocks in the following way:

Under conditions similar to those that give rise to quartz limestones, rocks having the bulk composition of gabbros have been metamorphosed into chlorite-epidote-albite rocks. This mineral facies has been called the *greenschist facies*.

[1] P. Eskola, "The Mineral Facies of Rocks," *Norsk geologisk tidskrift*, Vol. VI (1920), pp. 143–94.

Tremolite limestones correspond with transitional forms between the greenschist facies and another facies called the *amphibolite facies*, because a rock of gabbroid composition whose minerals have formed under the conditions of this facies, appears as a plagioclase-hornblende rock, an amphibolite.

The diopside limestones, so far as known at present, also belong to the amphibolite facies, and even some of the wollastonite limestones belong here, but the last named cover a wide range of temperature and pressure conditions corresponding to several kinds of mineral development in the silicate rocks, and a gabbroid material may give any one of the mineral combinations: plagioclase and clinoenstatite-diopside solid solutions (provisionally referred to as the *sanidinite facies*) or plagioclase, diopside, and hypersthene (*hornfels facies*), or diopside-jadeite solid solutions and pyrope-almandite solid solutions (*eclogite facies*).

Metamorphic limestone as a geologic thermometer can be calibrated against the transformation points of the silica minerals. The fact that quartz, and not tridymite, occurs even with wollastonite, would seem to indicate that the wollastonite-curve passes below the transformation point quartz-tridymite. This is, according to Fenner,[1] 870°, but it must rise somewhat with pressure. As to the transformation point α-β-quartz at 575°, it has been established that crystals of quartz in a diopside limestone from Parainen in southern Finland, have been originally α-quartz,[2] while the quartz-dolomite rocks of eastern Finland contain clear crystals of quartz which is apparently primary β-quartz. More observations on this subject are desirable.

It is to be hoped that the temperature-pressure curves for the different silicate-carbonate equilibria may be determined exactly by experiment, in the near future.

In the contact zones of the Becket gneiss in western Massachusetts three of these paragenetic types of limestone occur, namely: quartz limestone, tremolite limestone, and diopside limestone. The temperature was probably nowhere high enough to

[1] C. N. Fenner, *Amer. Jour. Sci.*, Vol. XXXVI (1913), p. 331.

[2] A. Laitakari, *Bull. Com. géol. Finl.*, 54 (1920), p. 40.

allow wollastonite to be formed,[1] and quartz is generally found in contact with calcite.

Quartz limestone is the most widely distributed type in western Massachusetts. Most of the Stockbridge limestone belongs to it and, also, much of the Coles Brook limestone. Such were the specimens from Goose Pond Creek and East Lee described above (p. 272). They consist of dolomite and quartz, sometimes with microcline.

During the excursions we did not happen to meet with any typical tremolite limestone, but it is apparent from Emerson's descriptions that it is a common type, in the Stockbridge as well as in the Coles Brook.[2]

Tremolite limestone is noted "south of Becket" (Emerson, *U.S. Geol. Surv., Mon. 29*, p. 27), and from Lee (*U.S. Geol. Surv., Bull. 159*, p. 84). Tremolite but no pyroxene in limestone is mentioned in the "Mineral Lexicon of Eastern Berkshire Co." (last-cited volume) from Windsor, Monterey, and the Cobble in Tyringham.

Through the courtesy of Mr. E. V. Shannon the writer was able to study specimens from the collections of the United States National Museum of tremolite limestone (Stockbridge) from Lee, Massachusetts, and from Canaan, Connecticut, near the Massachusetts line. The rock from both localities was found to consist

[1] Cf. footnote 1 on p. 285.

[2] It might be objected that it is not justifiable to regard the Stockbridge and the Coles Brook limestones as equivalents in their metamorphic development. For, if the former is Cambrian, while the latter, with the Becket gneiss intrusive in it, is pre-Cambrian, the Stockbridge cannot have been influenced by the heat of this intrusion which undoubtedly has changed the Coles Brook limestone. Now the plain fact is that the same three types of mineral paragenesis occur in both of them. The Coles Brook limestone, when belonging to the quartz type, is exactly like the most common type of Stockbridge limestone. The occurrence of tourmaline in the latter, recorded above, points to the vicinity of magmas. Emerson knew this, and he assumed that there may be post-Cambrian igneous masses not quite exposed on the present land surface. If this is true, then the earlier and the later intrusions have taken place during very similar physical conditions. It seems worth while, in future investigation of the geology of western Massachusetts, to consider the possibility that the Becket gneiss is of post-Cambrian origin, and the Coles Brook limestone only the margin of the Stockbridge. In fact our observations at the eastern as well as at the western contact of the Becket batholith seemed to indicate that this is the case.

of dolomite, calcite, and tremolite, with some brown mica ($\beta_D = \gamma_D = 1.582 \pm 0.003$), but no quartz. It thus proves to represent a true equilibrium under those temperature-pressure conditions which give rise to tremolite limestone.

Diopside limestone occurs so commonly that it is not necessary to name more than a few localities, as examples. Emerson[1] describes pyroxene- and actinolite-bearing limestone from Hinsdale and East Lee, both being Coles Brook limestone. His "Mineral Lexicon of Eastern Berkshire Co." (*op. cit.*) mentions pyroxene from the Stockbridge limestone from New Marlboro and several places in Tyringham.

The writer studied diopside limestone from Becket Station, a combination of calcite, quartz and diopside. It is a rock of the diopside limestone type. All the dolomite has been exhausted in the formation of diopside, while some quartz has been left.

Theoretical reasoning leads to the conclusion that the quartz-carbonate rocks, when they are metamorphosed under medium temperature conditions, corresponding to the tremolite and diopside limestone types, are likely to become poorer in dolomite. This must finally cause a dedolomitization of the limestone.

The silica need not occur within the limestones themselves, but may react at the boundaries. In small bodies of limestone bounded by highly siliceous rocks, and especially when submerged in magmas of such acid rocks, this may be expected to give rise to a perfect dedolomitization. So far as the writer's experience goes, small bodies of limestone inclosed in granites or gneisses really consist of calcite-rock, while magnesium-bearing silicates occur at their contacts. This rule was confirmed in the Massachusetts localities studied, near Benson Pond and near Becket Station.

ASSIMILATION OF LIMESTONE BY GRANITIC AND PEGMATITIC MAGMAS

The writer believes that the mode of occurrence of the clino-pyroxene gneiss around and near the occurrences of limestone included in the gneiss is in itself sufficient evidence that the gneiss has received its excessive amount of lime through assimilation of the limestone.

[1] *U.S. Geol. Surv., Bull. 159*, pp. 32 and 51.

We have found that the clinopyroxene gneiss has, in the majority of cases, a composition that is nearly the same as that of the ordinary Becket gneiss of the surrounding area, excepting that it has a higher amount of lime. A bulk composition may therefore be computed from the analysis of the gneiss quoted above (p. 268), by allotting CaO enough to form anorthite with all the excess alumina (actually present in the micas), to form diopside with all the (Mg,Fe)O present, and titanite with all the TiO_2 present. Such a calculation indicates practically no other change in the composition than an increase in the percentage of lime from 1.30 to 2.97 per cent. The rock would contain 25.2 wt. per cent quartz, while the actual Becket gneiss has 27.7 wt. per cent.

The actual clinopyroxene gneiss in many cases differs from this imaginary rock in being poorer in quartz, and having soda in excess over potash or potash over soda. The aplitic gneiss around the skarn inclusions near Benson Pond is an example of a highly potassic type low in soda and silica, being composed practically of potash feldspar only. The analyzed rock from south Peru, on the other hand, is an extremely sodic variety, low in potash and silica. In both cases practically all the excess silica is gone, and the feldspars and the pyroxene only have been left.

Where a magnesic clinopyroxene occurs in an acid gneiss it proves that the assimilation of limestone had happened nearly in place without further development, while the occurrence of pyroxene high in the iron compound, as was found in some cases, indicates that some differentiation had taken place after assimilation. Both cases occur in the banded Becket gneiss (cf. p. 277).

The *skarn* exhibits a special case. It is supposed to be a pneumatolytic contact-product formed in limestone in such a way that adjacent magmas have brought in silica and metal compounds which have replaced the carbonate.

It is pretty clear, in the case of the clinopyroxene gneiss in question, that it has been formed in part by direct assimilation of limestone by the gneiss magma and in part by the assimilation of skarn previously formed by contact action.

The main indication of the banded structure of the gneiss seems to be that its intrusion and crystallization has happened

under the conditions of stress and movements. The effective stirring together of the earlier solid materials with the newly intruded mass doubtless was one of the chief reasons why assimilation of limestone on a rather large scale has occurred here.

Very obviously some amount of assimilation of older silicate rocks associated with the limestone has also taken place. Some evidences to this effect have been presented by Emerson.[1] In its actual characters, however, the banded gneiss is altogether an igneous rock and its band structure is not by any means a direct result of injection combined with some kind of ultrametamorphism. Its whole structure is markedly different from that of such injection gneisses and migmatites known to me from many other regions and, also, from the eastern boundary zone of the Becket gneiss west of Chester.

We may make some comparisons with similar phenomena in other regions. Such clinopyroxene gneisses, or clinopyroxene granites, occurring in connection with limestones and evidently formed by assimilation of limestones surely do occur in many tracts. That they are little noticed may in part be due to their inconspicuous aspect and often imperceptible difference in the hand specimen from ordinary granites and gneisses. On the other hand, it is quite certain that they are not by any means regular associates of granites intruding limestones. I shall name some examples from my own experience.

My work in the Orijärvi region in southwestern Finland proved the absence rather than the occurrence of such products of assimilation of limestone, although it is an area where gneissic granites are intrusive into limestone-bearing formations. Only in a few places was the boundary type of the gneiss granite against limestone found to be diopside-bearing,[2] and only where it intersected limestone as dikes. None of the granites designated as "microcline granite," which are distributed all through southern Finland and very often cut limestones or contain inclusions of them, was ever found to contain clinopyroxene as a rock mineral, excepting in pegmatite dikes (cf. below). Similar relations have also been

[1] *U.S. Geol. Surv., Bull. 597*, p. 154.

[2] P. Eskola, *Bull. Comm. géol. Finl.*, No. 40 (1914), p. 61.

found obtaining in the well-known limestone-bearing area of Parainen (Pargas).[1]

Another feature with which the non-occurrence of assimilation is evidently connected is that this granite which forms veined gneisses or migmatites with all kinds of siliceous rocks has never been intruded into limestones to form intimate mixtures. Therefore the writer made the following general statement:[2] "The resistance offered by limestones against granitization is very remarkable. Even in the midst of a migmatite area, where all siliceous rocks have been thoroughly mixed or assimilated with the granite magma, the limestones are generally quite free from granitic injections, and are intersected only by rectilinear dikes." More evidence of assimilation of limestone by granite magma was brought forth during an investigation of certain areas in Transbaikalia.[3]

The peninsula of Sviatoy Noss, on the east coast of Lake Baikal, is made up of crystalline schists, among which are numerous masses of limestones, and of huge batholiths and smaller bodies of granites intrusive into the schists. The granites, when meeting limestone either as dikes or as large masses, show no endomorphic change whatever at the contacts, while in certain intrusive masses there is a very remarkable change in the whole rock bodies, the rocks (called sviatonossite) being composed of alkali feldspars with aegirite-augite and andradite. The high percentage of lime present has clearly been derived from the limestone, but the process of assimilation has taken place in such a way that andradite-clinopyroxene skarn has first been formed from the limestone and the skarn has subsequently been absorbed. This is evident from the common occurrence of fragments of skarn in the rock showing every degree of assimilation. Finally, all the minerals have crystallized out from the magma and the rock is now an ordinary unaltered igneous rock.

[1] Laitakari, *op. cit.*

[2] *Op. cit.*, p. 36.

[3] P. Eskola, "On the Igneous Rocks of Sviatoy Noss in Transbaikalia," *Översikt av Finska Vet.-Soc. Förhandlingar*, Vol. LXII, A, No. 1 (1921).

On the island of Gurskö, on the west coast of Norway,[1] the writer studied a large mass of crystalline limestone surrounded by an intrusive gneiss. At the boundary of the limestone there occurs a zone in the gneiss consisting of a banded clinopyroxene-oligoclase rock. This rock undoubtedly has obtained some of its lime by assimilation of the limestone, and its characters are, in so far as regards the structure and probable mode of intrusion and consolidation during vehement movements, closely similar to those of the western Massachusetts rocks.

In all cases mentioned, acid magmas have been enriched in lime derived from limestones and have crystallized as such without any considerable change of composition through differentiation. We shall not discuss here at all those processes by which alkaline rocks are supposed to form from igneous magmas which have assimilated carbonates.[2]

Diopside pegmatites in limestone regions.—While rocks, in occurrence and origin similar to the diopside gneisses described, are uncommon, there are in most limestone areas cut by granites, very numerous dikes of pegmatite containing diopside, titanite, and other lime-bearing minerals. Such pegmatites occur so commonly in the western Massachusetts area[3] and elsewhere, that we do not need to give any further examples. The large quantity of titanite present in many of these dikes is remarkable.

The writer's field evidence from southern Finland goes to prove that the assimilation of lime has taken place within the pegmatite fissures themselves and not in the granitic parent magmas of the pegmatite. This is well illustrated by the frequently observed feature that a pegmatite, cutting through limestone and other rocks as well, has developed much diopside and titanite only while intersecting the limestone, but is an ordinary mica pegmatite outside of the limestone.[4]

[1] P. Eskola, "On the Eclogites of Norway," *Vid. selsk. Skri. Mat.-naturv. Kl. I*, No. 8 (1922), p. 24.

[2] As the writer has suggested, the Sviatoy Noss rocks show an incipient stage of development toward "alkalinity."

[3] B. K. Emerson, *U.S. Geol. Surv., Bull. 597*, p. 19.

[4] Cf. A. Laitakari, *op. cit.*, p. 7.

The pegmatites, like other igneous rocks, show a varying behavior toward the limestones: The writer has seen, in several limestone areas, swarms of pegmatite dikes some of which carry clinopyroxene and titanite whereas others do not and could find no differences to which this might be ascribed.

The common occurrence of phenomena of assimilation in pegmatites interests us because it proves decisively that this process does not require any high temperatures. The pegmatites crystallize out from residual solutions which still exist in liquid form after the main igneous bodies have become solid. The common occurrence of β-quartz as well as α-quartz proves that the temperature has frequently been below their transformation point at 575° during the crystallization of pegmatites.

Now, what has been the temperature of consolidation of the diopside-bearing varieties of the Becket gneiss? If we could estimate this, we would know that the assimilation took place at slightly higher temperatures than that of the beginning of crystallization. This must have happened between the three-phase points quartz-calcite-wollastonite and quartz-dolomite-diopside invariant under the existing pressure. The higher of these points apparently lies below the inversion-point α-quartz-tridymite, but at present we cannot state it more closely.

The other minerals of the gneiss indicate that the temperature had decreased very much before crystallization was complete. The rock contains epidote as individual large grains associated with albite, the epidote probably not being entirely of secondary origin. The potash feldspar does not contain any threads of albite (perthite), a fact that might indicate that the temperature was so low when the microcline crystallized that no considerable amount of albite could be taken into solid solution to separate later and form perthite. Only the lowest-temperature pegmatites contain such homogeneous potash feldspar.

Turning finally to the question why limestone is assimilated in some cases and in others not at all, it seems that this may be largely dependent upon mechanical conditions. Assimilation is promoted, if the intrusion is connected with folding and the intrusive magmas are agitated and mixed with the crushed materials from

the country-rock. This is in accordance with the experience that assimilation usually occurs where the intrusive rock shows banded structure and a high degree of protoclastic crushing and shearing, while it does not occur in masses which have been intruded and crystallized under quieter conditions and have come in contact with the country-rock along smooth surfaces only.

It does not seem, however, that the whole question can be covered by this explanation only. There are no doubt differences in the physicochemical conditions, in the concentration of volatile compounds, etc., which cause assimilation to occur in one case and not in another. Such relations may be understood better as soon as more experimental evidence has been gathered about the solubility of carbonates in magmas.

SUMMARY

Within the area of the igneous Becket granite gneiss in western Massachusetts there occur several tilted up layers of crystalline limestone, called Coles Brook limestone, older than the gneiss and metamorphosed by its contact influence. In the vicinity of the limestone the gneiss contains considerable quantities of lime-bearing silicates, especially of clinopyroxene (diopside-hedenbergite) and titanite, apparently the result of assimilation of limestone by the gneiss magma.

The gneiss is markedly banded, with alternating darker and lighter bands. It was found, by determining the refractive indices of the chief mafic minerals, biotite, clino-amphibole, and clino-pyroxene, that the amount of their magnesia compounds in proportion to their ferrous compounds increases with the total quantity of the mafic constituents. At the same time the amount of anorthite in the plagioclase increases. Thus the dark bands behave like the earliest separated rocks in a differentiation series. Some differentiation by crystallization really seems to have taken place after the assimilation. In certain places, however, and especially at the immediate contacts against the limestone, the actual composition of the gneiss appears to be a direct result of assimilation and no correspondence between Fe:Mg ratio and "basicity" exists.—The distribution of magnesia and ferrous oxide among the different

mafic minerals was found to show a certain regularity, the mica always being richest and the clinopyroxene lowest in the iron compound. The variation of the "Fe-quotient" is believed to offer an important characteristic of crystalline rocks, though at present little understood.

When silica-bearing limestones are subjected to metamorphism there occur reactions between the carbonates and silica, and silicates of lime and magnesia are formed. The temperature of reaction varies with pressure and is different for different minerals formed, as pointed out by V. M. Goldschmidt. The writer's earlier investigations have established that, among the common accessory silicates in limestones, wollastonite requires the highest temperatures to form, and diopside and tremolite, successively lower. At still lower temperatures silica, in the form of quartz, remains uncombined. Thus we may distinguish the following types of metamorphic limestone: wollastonite limestone, diopside limestone, tremolite limestone, and quartz limestone. These types may be used, under certain conditions, as a geologic thermometer, and it is hoped that the equilibrium curves of the different silicates with the carbonates may soon be determined experimentally.

The limestones of western Massachusetts were found to represent all the above-named types excepting the wollastonite limestone. Their mode of occurrence harmonizes with the writer's earlier experience, diopside limestone occurring at the immediate contacts of the gneiss and tremolite limestone and quartz limestone successively farther away.

A review of the writer's experience from limestone-bearing regions where intrusive granites occur seems to prove that such phenomena of assimilation of limestone as those observed in western Massachusetts are not at all of regular occurrence. Preferably they seem to occur in those regions where gneiss magmas have been intruded in connection with mountain folding, thus being dependent on the mechanical conditions in all probability. It appears, also, that assimilation does not require very high temperatures, being a very common phenomenon in granite pegmatite cutting limestones.

A CRITICISM OF THE "FAUNAL RELATIONSHIPS OF THE MEGANOS GROUP" BY BRUCE L. CLARK

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In a recent paper[1] published in the *Journal of Geology* Dr. Bruce L. Clark revises the Eocene scale of California by introducing a new division, the Meganos group, by cutting off the lower portion of the strata which had previously been referred to the lower Tejon. Clark's essential basis for division is stratigraphy first recognized in the area north of Mount Diablo, Contra Costa County. After his recognition of an unconformity in this area, subsequent faunal work led him to assert a marked faunal break as well although he recognized that the fauna obtained from these beds "appears to be more closely related to the Tejon than to the Martinez." In this paper Clark deals with the general correlation of the middle and upper Eocene Sections of the Pacific Coast and he tentatively correlates his Meganos group with the Wilcox of the Gulf Coast.

Owing to his absence from the United States, the writer is unable to discuss this paper in detail, but there are certain general conclusions of Dr. Clark's to which he wishes to record a firm dissent.

The evaluation of an unconformity is frequently a difficult matter and in many cases only a close study of the faunas from above and below the line of unconformity will enable the paleontologist to determine the relative value of the time break recorded in the rocks. Now the recognition of the existence of unconformities within the Tejon Group is not new, and largely upon this account the writer has consistently clung to the term *group* in describing the Tejon as a stratigraphic and faunal unit. In making a study of the Tejon Group, its probable future division

[1] Bruce L. Clark, "The Stratigraphic and Faunal Relationships of the Meganos Group, Middle Eocene of California," *Jour. Geol.*, Vol. XXIX (1921), pp. 125–65.

FIG. 1.—Outline map of California showing (1) Mount Diablo region; (2) region north of Coalinga; (3) south end of San Joaquin Valley; (4) Camulos quadrangle; (5) Table Mountain, in the vicinity of Oroville.

into formations was constantly kept in mind. In the special case in point the writer regards the unconformity north of Mount Diablo as being such a one as would separate the Tejon group into formations, while Dr. Clark would make two groups. Dr. Clark admits that this unconformity was not stratigraphically recognized in the fine Tejon-Eocene section only a few miles distant on the south side of Mount Diablo.

> Detailed mapping has failed to show any marked difference in dip and strike between the Meganos and the Tejon in this southern area, such as occurs to the north of the mountain (Mount Diablo). At a few localities there is an apparent difference in dip between the beds of the two horizons; this, however, could not be verified with certainity, the division being recognized by a sharp change in lithology, and by faunal evidence [p. 141].

The footnote on this same page is likewise significant:

> In the former paper ["Meganos Group, a Newly Recognized Division in the Eocene of California," *Bull. Geol. Soc. America*, Vol. XXXIX (1918), pp. 281–96] referred to above, the writer stated that in this section there is a marked difference in strike between the Meganos beds and those of the Tejon, and the difference was taken as one of the evidences of unconformity between the beds of these two horizons. Later work, however, has shown that this apparent difference in strike is, in part at least, the result of faulting. Also it was stated that to the east of this area the Meganos disappeared due to this unconformity. At that time the writer had not recognized that the so-called Tejon beds to the east, as described by Dickerson, were in part Meganos.

Concerning the presence of unconformities in other parts of California, Clark refers to his studies made in the vicinity of Coalinga and Simi Hills, Ventura County, as follows:

> The results of this work show conclusively that beds of both Meganos and Tejon age are present in all of these areas, and that there is in each an unconformity separating the strata of those two series.[1] . . . . As seen between . . . . Domengine Creek and Cantua Creek (Coalinga Quadrangle), the upper beds of the Meganos consist of a white sandstone which was mapped by Anderson and Pack as a part of the Tejon. The contact between the Meganos and Tejon comes in between this sandstone and somewhat similar sandstones of the Tejon. It is, as a rule, marked by a conglomerate and is irregular at numerous localities. The sandstones below the contact, due to the unconformity, thicken and thin very noticeably along the strike. Also, at a number of localities the lower sandstones show a dip and strike appreciably different from those of the Tejon beds above. While these differences amount

[1] Evidently series is used loosely.

at the most to only a few degrees, it is sufficient to cause the lower sandstone layers to be cut off obliquely, and on the cliff sections they are seen to abut against the basal beds of the Tejon [pp. 143–45].

The writer cannot see how "the sandstones below the contact, *due to the unconformity* thicken and thin very noticeably along the strike" but rather thinks that the beds were deposited near shore and that the sandstone lenses into shale or the shale gradually grades into sandstone. If memory is correct, Anderson and Pack's mapping indicates that several comparatively thick members exhibit this same phenomenon on a great scale. Anderson and Pack, F. M. Anderson, Clarke Gester, and J. A. Taff had good opportunities to study this section and as far as I recall none of them recorded any notable dip differences. The writer did not do extended field work in this section, but from what was observed, he believes that careful search will bring to light several erosional unconformities in the region. That is, the Tejon group in this region was deposited under strictly littoral conditions, and from time to time comparatively slight emergences of the Eocene continental strand line are recorded by these erosional unconformities. Dr. Clark states that the lithology of the sandstones above and below this unconformity are essentially similar. This similarity is so close that a series of hand specimens from above would not be separable from a series from below if the two were mixed. Depositional conditions over the present sites of Simi Hills region and vicinity of Grapevine Canyon are characteristically littoral as indicated by both the fauna and the lithology.

The fauna of only fifteen species listed by Clark from San Emigdio Canyon on page 149 is entirely too meager upon which to base definite broad conclusions. Of these, eight are new species, one is only generically determined, two are doubtfully referred to described Eocene species. However, it is quite possible that the Turbinolia Zone of the Tejon Group (Meganos Group of Clark) may be present here.

Dr. Clark assigns the *Siphonalia sutterensis* Zone of Dickerson to his Meganos Group largely upon faunal grounds, since *Turritella merriami*, *Ancilla* (Oliverato) *californica*, and a few other forms are found at Oroville, Marysville Buttes, in the vicinity of Mount

Diablo, Camulos Quadrangle, and the Coalinga region. On pages 130 and 131 Clark states that

> After discussing the various Eocene sections, reasons will be given for correlating the beds referred to the Meganos group in these different areas in the Coast ranges with one another and with the marine Ione formation in the Sierra Nevada foothills, as mapped and described by Lindgren and Turner *not, however, including the type section of the Ione.*[1]

Why not discuss the type Ione? It is well described and at one locality has yielded a fair but determinable marine fauna containing Turritella *merriami* and other typical Tejon species. Also the strata of the type Ione clearly intergrade with the Tertiary Auriferous gravels of the Sierra Nevada foothills. Now the type Ione may be traced southward and connected with the Marine Eocene strata a half-mile south of Merced Falls where specimens of *Venericardia planicosta merriami* may be collected in abundance. Farther south, the stratigraphy of the Ione clearly demonstrates deposition by a sea transgressing from the west. North of the type section of the Ione, Lindgren and Turner have traced these beds through to Oroville. Dr. Clark in his historical review quotes from Dickerson's "Note on the Faunal Zones of the Tejon Group" as follows:

> A study of the relationship between zone 3, Mount Diablo region, and the Siphonalia sutterensis zone and their geographic position suggest that the uppermost strata of the Marysville Buttes and Oroville were deposited by a transgressing sea, and that only in favored places along the western borders of the Sierra have the latest Eocene sediments been preserved from erosion. Lava caps such as that of the older Basalt of South Table Mountain have preserved these youngest Tejon sediments which have heretofore been regarded as Ione.

This quotation creates the impression in the reader's mind that Dickerson's concept of the Tejon-Ione relations was purely theoretical, whereas such is not the case. The stratigraphy of the Ione at Bear Creek 20 miles south of Merced Falls, at Merced Falls, at Ione, at Oroville, all clearly indicate deposition by a transgressing sea in close proximity to an old Eocene shore. Into this Eocene sea the streams of the low mountainous Eocene upland poured their golden sands. The reader is referred to Dickerson's paper, "Stratigraphy and Fauna of the Tejon Eocene of California," for a full

[1] Dickerson's italics.

discussion of these essential matters. Clark has evidently missed the significance of this evidence as he states on page 162 of his paper that

> Dickerson attempted to establish the stratigraphic sequence of his upper faunal zone in relation to that of the typical Tejon indirectly, not having the two faunas in the same section. His idea that the Siphonalia sutterensis fauna is younger than that of the typical Tejon appears to have been founded principally upon what he considered evidence for different stages of evolution of certain pelcypods, such as *Venericardia planicosta merriami* Dickerson and *Cardium marysvillensis* Dickerson. He believed that the variety *merriami* was derived from the variety *hornii*. Later stratigraphic work has shown that these species occur in a sequence the reverse of that which Dickerson originally supposed, the *Venericardia planicosta merriami* coming in beds older than those containing the variety *hornii*. The same is true of the other species, which were derived from typical Tejon species.

It is true, however, that the problem of Ione-Tejon relations was attacked with faunal weapons as well. Clark states that "Later stratigraphic work has shown that these species occur in a sequence the reverse of that which Dickerson originally supposed. . . . ." In the historical review on page 129, Dr. Clark reviews a short paper, by Arnold and Hannibal, and includes the following quotation from it:

> The writers have shown that in Oregon and Washington the Eocene may be divided into three faunal divisions, the Chehalis, Olequa, and Arago or Ione formations. The Chehalis formation is characterized especially by *Venericardia hornii* Gabb, Meretrix *californica*, *Pecten* (*Chlamys*) *landesi* or *Venericardia hornii* Gabb and a tropical flora, and the Arago or Ione formation by *Turritella merriami* Dickerson, a form of *V. hornii* with obsolete ribs (var. *aragonia* A. and H.), and a tropical flora.
>
> The Arago or Ione beds represent a horizon younger than any Tejon recognized in the Tejon or Puget Basin. The Arago or Ione beds occurring as they do in basins distinct from those in which the Tejon series is developed, and being formed at a different period, must be treated as a distinct division of the Eocene.

[1] Arnold and Hannibal use formation as an equivalent for faunal zone or horizon and loosely use *formation, group, series*. The form referred to as *V. hornii* var. *aragonia* A. and H. was not described by them but was collected at the type locality of *V. planicosta merriami*, on Little River, Roseburg Quadrangle, Oregon. Arnold and Hannibal classed these beds as Arago (or Ione).

In connection with this statement Clark refers to Weaver's stratigraphic studies wherein Weaver shows that the Olequa and Chehalis of Arnold and Hannibal were reversed. Weaver's careful work cleared up this succession but apparently does not invalidate Arnold and Hannibal's assignment of the Arago as the uppermost formation of the Eocene. Arnold and Hannibal regard the type locality of *Venericardia planicosta merriami*, on Little River, Roseburg Quadrangle, Oregon, as being in the uppermost portion of the Eocene, their Arago formation, and in this general conclusion the writer is in agreement. The evidence yielded by evolutionary forms of *Venericardia planicosta* have not been sufficiently studied by Dr. Clark. The first of these forms is *V. planicosta venturaense* Waring and was described from the Martinez (Lower Eocene) of the Simi Hills, Ventura County, California. Waring's type was considerably eroded but a mature specimen collected from near the type locality by the writer shows strong V-shaped ribs marked by very prominent nodes. Now these characters are conspicuous only in the youthful stages of *V. planicosta hornii* Gabb, the nodose character disappearing rapidly as the specimen matures. In very youthful specimens of *V. planicosta merriami* the same characters appear but these forms upon reaching maturity are marked by nearly complete obsolescence of ribs as well.

Clark, in the writer's opinion, overemphasizes the presence of new species in the Eocene and permits this to color his views. It is the writer's experience that in California, where unusually good preservation is found, many new species will be discovered. We must not lose sight of the fact that the pelecypod and gastropod fauna of the Tejon group is probably not much more than half-described. And on this account we must not create new horizons, based largely on such evidence. Again, let us not forget that the Tejon group is largely composed of inshore or strictly littoral sediments, and that the lignite seams occurring commonly throughout California, Oregon, and Washington, generally indicate deposition in lakes or lagoons bordering the Eocene shore. Thus during the deposition of the upper Tejon north of Mount Diablo three different carbonaceous beds were laid down, and there is evidence to show that the sea was at least temporarily withdrawn while these lignitic

strata were being formed. In other words, minor unconformities are here present. Sixty miles east of Mount Diablo there is a ten-foot seam of coal at Ione in the type section. Now if Clark is right in correlating the Ione with his Meganos group, then the Meganos group is again broken by an unconformity, since several hundred feet of Eocene sediments underlie the Ione coal seam which rests unconformably upon them.

Along the foothills of the Sierra Nevada in the undisturbed, nearly horizontal Eocene beds many interesting data are yet to be secured, as here the old Eocene shore is traceable and the streams of the old Eocene peneplain are still preserved beneath thick lava for the inspection of some untiring geologist interested in reconstructing the past of this wonderful land.

THE AGE OF THE DOMES AND ANTICLINES IN THE LOST SOLDIER–FERRIS DISTRICT, WYOMING[1]

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INTRODUCTION

The relative age of the major and minor folding in Wyoming is a somewhat mooted question among geologists, especially among those who are interested in the problems of oil and gas accumulation. In a recent paper Ball[2] reached the conclusion that nearly all the minor folds of Wyoming were formed during the period of formation of the major uplifts. That exceptions to this general rule may exist is frankly admitted by Ball, and he cites the Simpsons Ridge fold as the one example with which he is familiar of an uplift in which the minor folding is clearly younger than most of the major folding. Although agreeing in general with Ball's conclusion, the writer believes that exceptions to the rule are more numerous than Ball suggests. He believes further that a most noteworthy exception to the rule is to be found in the folds of the Lost Soldier–Ferris oil and gas district of south-central Wyoming, the age relations of which are here discussed.

GEOGRAPHIC AND GEOLOGIC RELATIONS

The Rawlins uplift, in south-central Wyoming, is about fifty miles in length and twenty miles in width and trends in a northerly direction (see map). It is not large enough to be classed among

[1] Published with the permission of the Director of the United States Geological Survey. The information presented in this paper was obtained in the summer of 1920, during an examination made to obtain data for classifying the public land in the oil and gas fields of the Lost Soldier–Ferris district. The results of this examination are being prepared for publication by the United States Geological Survey.

[2] Max W. Ball, "The Relative Ages of Major and Minor Folding and Oil Accumulation in Wyoming," *Amer. Assoc. Petroleum Geologists, Bull.* 5 (1921), No. 1, pp. 49–63.

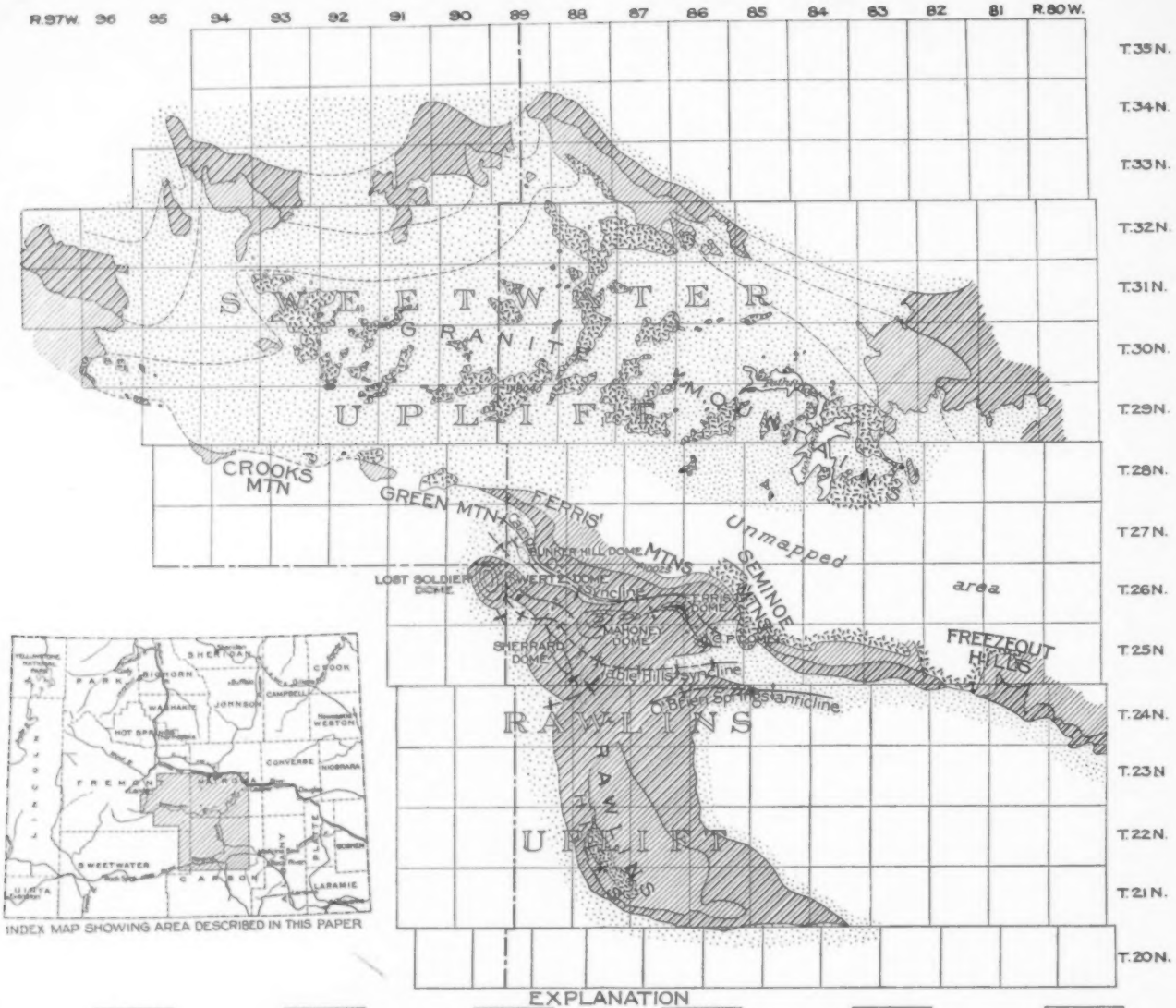
the major uplifts in Wyoming on account of its size, but the fact that its central axis is elevated so high that the pre-Cambrian rocks are now exposed at the surface is sufficient, as pointed out by Ball,[1] to justify ranking it as a major uplift. Its alignment makes it a part of that series of Rocky Mountain flexures characterized by northerly lines of folding and faulting. It is to be noted especially that the Rawlins uplift is one of a group that forms the northernmost member of this northerly series, beyond which the Rocky Mountain folds abruptly change in direction to a transverse series with east-west trend, of which the Sweetwater uplift, described below, is one.

From the general horizontal position of the Wasatch beds on the west flank of the Rawlins uplift, it seems certain that the development of this uplift was complete, or practically complete, by the beginning of Wasatch time.

The central pre-Cambrian granite core of the Rawlins uplift is faulted along its west side, and toward the north this fault zone turns northeastward and crosses the axis of the fold. The portion of the uplift north of this fault is on the down-dropped side, and this lower-lying north end of the uplift is occupied by the oil and gas fields of the Lost Soldier–Ferris district. The oil and gas accumulations of this district are controlled by minor folds, and it is these minor folds that constitute the subject of this paper.

North of the Rawlins uplift is the Sweetwater uplift, a major fold about one hundred miles long and forty miles wide that trends nearly due east. The Granite Mountains, which occupy the central part of this uplift, represent the higher peaks of the much dissected pre-Cambrian crystalline rock core, whose valleys and lower-lying parts are now filled and covered by nearly horizontal Tertiary sediments. These sediments form a nearly flat plain, above which the Granite Mountains rise like islands in a sea. On the south margin of the Sweetwater uplift, immediately adjacent to the Lost Soldier–Ferris district, are the Ferris and Seminoe mountains. The north side of the Ferris Mountains consists of pre-Cambrian crystalline rocks, adjacent to which, in a sharply upturned attitude, lie the Paleozoic and Mesozoic sediments that

[1] Max W. Ball, *op. cit.*, p. 51.



GEOLOGIC MAP OF THE RAWLINGS AND SWEETWATER UPLIFTS, WYOMING

form the south side of the mountains. In some places high on the flanks of the mountains the sedimentary beds are vertical or even slightly overturned.

To the southeast of the Ferris Mountains this sharp folding is replaced by faulting with thrust from the north, so that the crystalline rocks of the Seminoe Mountains now lie against the Cretaceous rocks of the Lost Soldier–Ferris district. The fault plane along which this overthrusting took place probably was almost vertical, and the horizontal displacement therefore slight, but even so the adjacent sedimentary beds of the Lost Soldier–Ferris district are somewhat overturned. It seems very probable that this overthrusting continues eastward as far as the Freezeout Hills. Westward from the Ferris Mountains the folding changes into faulting, but in this direction the amount of overthrusting is not so great as to the southeast.

The Sweetwater uplift, like the Rawlins uplift, is considered to have been developed mainly in pre-Wasatch time, but it differs from the Rawlins uplift in that the main deformation was followed by later movements of considerable magnitude. The importance and relations of these later movements are discussed below.

AGE OF THE FOLDS

The points to be brought out are two: (1) The folds of the Lost Soldier–Ferris district were not produced by the same forces that formed the Rawlins uplift, on which they were superimposed, but were produced by the forces that formed the Ferris and Seminoe mountains, to the north and northeast. (2) The Ferris and Seminoe mountains are considerably younger than the Sweetwater uplift, on whose south margin they rise, and probably represent a relatively late readjustment along this margin. If these points are established it follows that the folds of the Lost Soldier–Ferris district are younger than the Rawlins uplift and also younger than the main development of the Sweetwater uplift.

1. With the geographic setting of the Rawlins and Sweetwater uplifts in mind (Pl. III), attention should be directed to the alignment of the minor folds in the Lost Soldier–Ferris district. The downfold that structurally separates the Rawlins and Sweetwater

uplifts is the sharply flexed Camp Creek syncline, which lies only a few miles south of the Ferris and Seminoe mountains. It parallels the direction of the fault line along the southwest side of the Seminoe Mountains. North of this syncline there are no minor folds on the south slope of the Sweetwater uplift, but instead the abrupt upfold and thrust of the uplift itself, which is represented topographically by the Ferris and Seminoe mountains. South of the Camp Creek sycline the Rawlins uplift is represented by a long, comparatively gentle slope up to the granite axis of the upfold in the Rawlins Hills. This gentle north and northeast slope is interrupted by minor folds, including a long upfold that extends from the Wertz dome at the west and is accentuated in its eastward course by the Mahoney, Ferris, and G.P. domes. As the surface rocks are concealed by dune sand and alluvial wash the exact course of this upfold is not well known except at the high points mentioned. The axis of this upfold is parallel not to that of the Rawlins uplift but to that of the Camp Creek syncline, which in turn lies parallel to the Ferris-Seminoe line of deformation. From this close parallelism of structure it would appear that this minor upfold is the result either of the same forces that produced the Ferris and Seminoe mountains or of similarly directed forces. Certainly it could not have been the result of the forces that formed the Rawlins uplift. The north flanks of the Wertz and Mahoney domes and the northeast flanks of the Ferris and G.P. domes are steeper than the opposite flanks, a relation which also helps to indicate that the forces which formed them probably came from the north and northeast. To the north of the Wertz dome is the small Bunker Hill dome, which lies parallel to both the Wertz dome and the Camp Creek syncline. The course of the synclinal fold lying immediately south of the Wertz–Mahoney–Ferris–G.P. upfold is not clearly defined, although the syncline that separates the Mahoney dome from the Sherrard dome, and the Wertz dome from the Lost Soldier dome, is probably the westward extension of the Table Hills syncline. It was this downfold which divided the north end of the Rawlins uplift and formed the Lost Soldier dome as a distinct feature from the Wertz–Mahoney–Ferris–G.P. upfold, to the east. By considering the Table Hills syncline to have a westward extension, as above mentioned, its course also shows a

transverse direction to that of the Rawlins uplift and a parallelism to the Ferris-Seminoe line of deformation. The O'Brien Springs anticline, still farther south, shows a similar trend.

From the considerations above set forth it seems reasonable to suppose that the minor transverse folding in the Lost Soldier–Ferris district on the Rawlins uplift was produced by compressive forces that came from the direction of the Sweetwater uplift, to the north; and from the parallelism between these folds and the Ferris-Seminoe line of deformation, it seems reasonable to suppose further that these minor folds represent the more distant effects of the same forces that formed the Ferris and Seminoe mountains.

2. If the truth of the preceding arguments is conceded, there remains, to complete the purpose of this paper, proof that the minor folds of the Lost Soldier–Ferris district are decidedly younger than the major Rawlins uplift and the main development of the Sweetwater uplift. It has been shown that the axes of the minor folds are transverse to those of the Rawlins uplift, a relation which in itself implies, although it does not necessarily prove, that the minor folds are more recent than the uplift itself. The best proof, however, is to be found in showing that the Ferris and Seminoe mountains, which are of the same age as the minor folds of the Lost Soldier–Ferris district, are considerably younger than the main development of the Rawlins and Sweetwater uplifts.

The Ferris and Seminoe mountains may be spoken of as a marginal rim to the Sweetwater uplift. The central core of this uplift, now represented by deeply eroded granite, is a structurally much more highly elevated part of the uplift than the Ferris and Seminoe mountains at its margin. It is possible that at the time of the main deformation the central core of this major uplift was elevated to several times the height of the marginal rim; but the particular fact to be noted is that the Ferris and Seminoe mountains now attain a maximum altitude of 10,025 feet (as determined by triangulation and vertical angles), a considerably higher altitude than that of the peaks of the Granite Mountains, which now form the core of the uplift, and whose highest point, Hayden Peak, is reported by Hares[1] to have an altitude of only 8,040 feet. This

[1] C. J. Hares, "Anticlines in Central Wyoming," *U.S. Geol. Survey Bull. 641* (1916), p. 234.

difference of nearly 2,000 feet in altitude cannot be due to difference in erosion alone. Moreover, the Granite Mountains now show smooth surfaces, whereas the Ferris and Seminoe mountains are rough and rugged, a difference which indicates that the Ferris and Seminoe mountains are in a more youthful stage of erosion.

From these differences in altitude and in character of topography, therefore, it appears clear that the present Ferris and Seminoe mountains are younger than the Granite Mountains. This conclusion further indicates that the Ferris and Seminoe mountains are probably the result of a relatively late readjustment along the south margin of the Sweetwater uplift, and, from the nature of the structural features in this region, that this later deformation was a slight overthrust in which the Sweetwater area moved southward toward the Rawlins uplift.

How much later in geologic time than the main development of the Sweetwater and Rawlins uplifts this readjustment took place is not readily ascertainable. From unpublished field information pertaining to T. 28 N., Rs. 90 to 95 W., along the south edge of the Sweetwater uplift, gathered by Hares just beyond the south margin of the area covered in his report on "Anticlines in Central Wyoming,"[1] and by Smith along the north margin of the area covered in his report on "The Eastern Part of the Great Divide Coal Field, Wyoming,"[2] it is clear that there has been considerable readjustment in these townships since pre-Wasatch time, when the major upfolds were first developed. The significant evidence along this marginal zone is to be found in the nearly flat-lying Tertiary formations (Wasatch?) in the Green and Crooks mountains, at altitudes of 1,000 feet or more above the nearly flat-lying Tertiary beds (Wind River and White River formations) of the basin that now marks the Sweetwater uplift. It is also an interesting fact that the White River (Oligocene) formation of the Sweetwater basin—the "sea" in which the Granite Mountains stand out as "islands"—seems to be limited on the south by the fault zone that marks the boundary between the pre-Cambrian rocks of the Sweetwater uplift and the Paleozoic and Mesozoic formations in

[1] C. J. Hares, *op. cit.*, pp. 233–79.

[2] E. E. Smith, *U.S. Geol. Survey Bull. 341*, pp. 220–42.

T. 28 N., Rs. 89 to 95 W.[1] This greater altitude of the nearly flat-lying Tertiary beds south of the Sweetwater uplift and the possibility that the White River and Wind River formations lie only on the uplift itself are indicative of a readjustment movement here in post-Wasatch time and possibly as late as White River time. Ball[2] mentions the fact that the Hanna formation (Wasatch?) is vertical and overturned in the Freezeout Hills.

There has even been some post-Pleistocene movement in the region, for gravel-covered terraces in some places are reported to have slopes opposite to those of the present drainage.[3] These comparatively recent movements were probably of small magnitude and are cited principally to indicate that deformation did not necessarily cease here in the Tertiary period, but that warping has occurred in the Quaternary. It is possible that deformation has taken place even within recent times.

Inasmuch, therefore, as mountain-forming deformation has occurred here in post-Wasatch time and possibly as late as White River (Oligocene) time, or even later, it would seem that the Ferris and Seminoe mountains should be regarded as the local results of this late movement of readjustment along the south margin of the Sweetwater uplift. Although the exact time when these mountains were formed has not been ascertained, it seems nevertheless that they must be considerably younger than the main deformative movements which produced the Sweetwater and Rawlins uplifts. If it is regarded as established that the Ferris and Seminoe mountains are due to a late and possibly final spasm of mountain-forming movements in this general region, it should probably be conceded that the minor domes and anticlines of the Lost Soldier–Ferris district are also due to the same movements. Credit must be given to Ball[4] for his recognition of a marked difference between the deformation features of the Ferris and Seminoe mountains and those of the Wyoming mountains of the

[1] No positive statement to this effect can be made, for the relation was noted over only a small area by the writer, and the evidence gleaned from the unpublished work of Hares and Smith above cited, though apparently supporting the inference, does not fully confirm it.

[2] *Op. cit.*, p. 55.

[3] K. C. Heald, personal communication.

[4] *Op. cit.*, p. 59.

usual type, but although he realized that this difference existed, he did not consider its significance in relation to the age of minor folds of the Lost Soldier–Ferris district.

ECONOMIC CONSIDERATION

The minor folds of the Lost Soldier–Ferris district are shown above to be distinctly younger than the Rawlins uplift, on which they are superimposed, and the question arises as to the relation of this difference in age to the accumulation of the oil and gas in the Lost Soldier, Wertz, Mahoney, Ferris, and G.P. fields. As the Rawlins uplift was in existence in pre-Wasatch time, it is obvious that any oil and gas that prior to the minor folding of the Lost Soldier–Ferris district had been formed or had migrated a short distance above the margin of the uplift, where the catchment areas of the present fields are situated, must surely have been lost through the eroded edges of the formations on the top of this major uplift. The oil and gas of the present fields and of possible unproved pools in this region must have been formed largely by the dynamo-chemical action of the later deformational forces that caused the minor flexing. Some oil and gas of earlier distillation may have been already present within the catchment areas of the existing fields, but this oil and gas must have been only a fraction of that which was formed within the area embraced by the Rawlins uplift. The oil and gas now available in this district for the use of man must represent, therefore, merely a remnant of the total quantity derived from the mother-material which the rocks of this region originally contained.

ON THE OCCURRENCE OF AN APUS IN THE PERMIAN OF OKLAHOMA

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Professor J. W. Beede last year sent two specimens of a crustacean from the Permian of Oklahoma to the New York State Museum for investigation. They were from a suite collected by Dr. Thomas T. Jackson in a thin sandstone bed of the Enid formation, exposed "on the top of a hill four or five miles north of Elkeno, Oklahoma."

The specimens[1] proved, on inspection, of exceptional interest for the reason that they not only exhibit an outline of the carapace as seen in Apus but even the impressions of the "shell-glands" or excretory organs in a form as it is today known in Apus, and its close relative Lepidurus. We have, therefore, no hesitation in considering this Permian form a true Apus, and propose for it the name *Apus beedei* sp. nov.

Apus beedei sp. nov.

Description.—Carapace small (the larger specimen 15 mm. × 14 mm.); broadly elliptic, nearly circular in outline, with a small posterior emargination; shieldlike and sloping from the subcentral apex abruptly forward, more gently backward, and probably originally fairly steeply toward the lateral margins. A transverse cervical fold is situated about one-fifth of the length of the carapace posterior to the anterior border. Immediately posterior to this are the large but slightly curved "shell-glands" or excretory organs; beginning at either side of the median line they extend obliquely backward about midway of the lateral faces of the

[1] Professor Beede had stated in his letter that he had more specimens than the two sent but none showing features not seen in the ones inclosed. On inquiry, we learn that this further material is not available at present, but in view of Professor Beede's statement and the great interest of the material, we venture to publish this notice without having had access to the less favorably preserved specimens.

carapace to about one-fifth of the length of the carapace from the posterior border. The median line is marked behind the cervical fold by a distinct depression extending about one-third of the distance toward the posterior border.

Horizon and locality.—Permian (Enid formation), near Elkeno, Okla.

Note on identification with Apus.—The writer is well aware that considering the enormous stretch of time from the Permian to the present time, and further the fact that only the carapace of the

FIG. 1

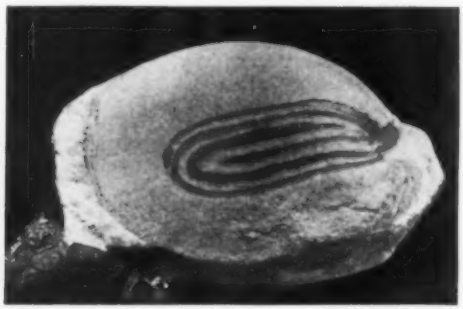

FIG. 2

FIG. 1.—*Apus beedei* sp. nov. The two specimens seen obliquely from above and the front. Natural size. The type-specimen is on the right. It shows the transversal wrinkle in the place of the cervical fold, portions of the frontal part of the carapace and the median depression.

FIG. 2.—*Apus beedei* sp. nov. Lateral view of the type-specimen. ×3. Shows the shell-gland and posterior emargination.

Permian form is now at hand, there is a great possibility that if the body of the animal were preserved, differences of generic importance might be quite apparent, e.g., such as now separate Lepidurus from Apus and which consist in the different development of the post-anal plate. It could, therefore, be urged that this Permian form should be made a separate genus on theoretic grounds. In such an attempt it would, however, be found that the carapace of the older form is not distinguishable from that of the recent type and the new genus would have no diagnosis, but only its great age to stand on. It is, however, to be understood

that the term Apus expresses here the hard parts only and the entire group (Apus and Lepidurus) and that it is merely intended to point out the persistence of the Apus-type of carapace. The persistence of the exact form of the carapace in the group indicates that no evolutionary development profound enough to affect the carapace took place in all this time.

Note on preservation of material.—The specimens are casts of the interior surface of the carapace. It is for this reason that the impressions of the shell-glands are so well preserved in some of the fossils, for it must be remembered that these organs are situated between the two layers that form the posterior portion of the

FIG. 3

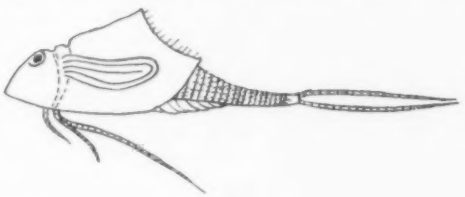

FIG. 4

FIG. 3.—*Apus beedei.* Flat projection of outline of carapace.

FIG. 4.—Lateral view of *Apus aequalis* Packard, ×2; from Colorado and in N.Y. State Museum.

carapace, and that these glands open where the inner layer terminates at the cervical fold. The frontal portion of the carapace is poorly preserved, partly no doubt on account of the greater thinness of the carapace there, which consists of but one layer, and partly owing to the lateral compression of the tests during entombment. There is, however, enough left of the frontal outline (especially in the smaller specimen) to leave no doubt that it was rounded and unbroken originally. It would seem that the shield was sufficiently sloping toward the lateral margins to come frequently to rest on the side and then suffer lateral compression. The amount of lateral slope is greater also in the recent Apus than the usual dorsal views of the creatures would suggest, as shown in the lateral view drawn from nature by the writer and reproduced in Figure 4. A restoration of the dorsal view of the carapace of *Apus beedei* is given in Figure 3. It is obtained by plotting the

larger specimen, in natural size, on the horizontal plane. An oblique view from above of the same specimen is given in Figure 1 and a lateral view in Figure 2. The former presence of a cervical fold in the Permian form, corresponding to that in recent species of Apus (Fig. 4, where it is shown in the profile behind the eye), is indicated by a transverse wrinkle, especially distinct in the larger specimen, but also seen in the smaller one. This wrinkle has resulted from the yielding of this transverse fold during lateral compression. It has thereby become pressed downward and changed into a deep transverse wrinkle, in front of which the carapace has split and been drawn inward. The smaller specimen retains the frontal portion in more perfect form, though also much compressed. Owing to this folding-in of the frontal part, the perforations of the carapace for the eyes are not observable.

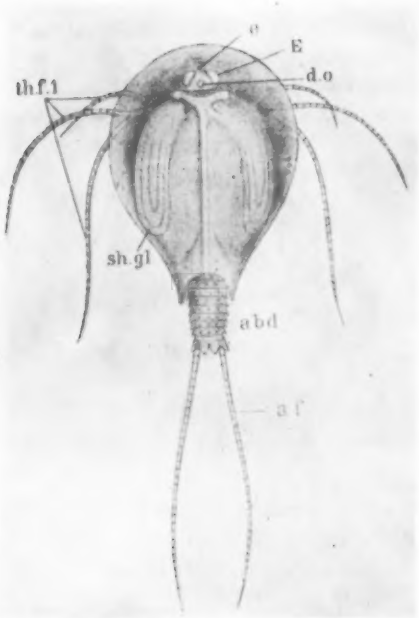

FIG. 5.—*Apus cancriformis* Schäffer. Dorsal aspect. From Parker and Haswell (after Bronn's Thierreich). *d.o.*, dorsal organ; *E*, paired eye; *e*, median eye; *sh. gl.*, shell-gland.

The shell-gland appears as an elongate elliptic body consisting of two concentric furrows and one median and another outer longitudinal one. There are thus altogether six urinary tubes counted on the transverse line, just as in the recent Apus (Fig. 5). All these are very distinct on both sides of the larger specimen and also well recognizable on the smaller one. They bend inward and

downward at the cervical fold, where as in the recent form they open (at the underside of the body).

The median line of the carapace is marked in its anterior third behind the cervical fold by a deep depression, fading out backward, which corresponds to the carina seen in *Apus cancriformis* and some of its congeners.

The posterior emargination is distinct in both specimens though not appearing in the photographs. The original of Figure 2 is just sufficiently compressed obliquely to have the emargination transferred to the other side.

General bearing of discovery.—Apus has long been famous in paleontologic literature as a primitive phyllopod that on account of its great number of simple appendages and other primitive features has served well as a model for comparison with extinct crustaceans, especially with the trilobites; and again in the case of the wonderful middle Cambrian branchiopods discovered by Walcott in British Columbia. It is equally famous among zoölogists for its strange life-cycle as well as its archaic characters. Notwithstanding its frequent citation in paleontologic literature, a true Apus has only once been found in fossil state. This is the *Apus antiquus* Schimper from the Buntsandstein of the Vogesian mountains. This find carried the range of Apus back to the Triassic, and the occurrence in Oklahoma extends it now to the Permian.

Apus is thereby made one of the few persistent types that have existed from Paleozoic to recent time. Like Limulus it is a "living fossil." Connected with this amazing persistence is undoubtedly the strange life-cycle of this creature, as the writer will elaborate more fully in another paper. Apus, as typically represented by *Apus cancriformis*, appears only at long intervals, usually only after decades of years, during which the eggs were buried in the dry mud of roads, ditches, and desiccated pools and exposed to heat and cold. It is therefore an extremely rare animal and the writer still remembers with thrill, how when still a schoolboy he one day espied a large specimen crawling on the muddy bottom in the water of a swamp along which he was botanizing,

rushed in, grabbed the strange creature, and ran back at top speed to the high-school professor of biology who promptly took it away declaring it to be the first he had ever seen alive! It is told of Goethe that he had one brought to him while walking once near Jena and that he became so excited over the weird animal that he offered a thaler for the second, a guilder for the third specimen, and so forth, but no other was found. *Apus cancriformis* grows within two weeks to full size which sometimes is nearly five inches, lays an enormous number of eggs and dies.[1] Another strange fact connected with this animal is that it produces the eggs parthenogenetically. It was fully a hundred years after the description of the species that any males were found. The seventy pairs of appendages (among them fifty-two pairs of abdominal feet with their gill-appendages) which give it its archaic appearance are also connected with its life in very temporary pools that lack the vegetation which oxygenates the water.

All these facts show that the animal is adapted to most peculiar, and it would seem also most precarious, conditions. It has been therefore thought by some, as Salter and Packard,[2] to be, together with the rest of the Branchiopoda, highly specialized and comparatively modern. Its fossil record, however, contradicts this conclusion, and from evidence, which the writer[3] in a former paper on arrested evolution has brought forward in regard to the factors of persistence in animals, it follows that Apus belongs to that class of persistent forms, that, at the height of their once vigorous development, were able to penetrate into fields where weaker forms could not follow them and it is precisely in these outskirts of the arena of organic struggle that these types, after they were overtaken by more rapidly developing forms, have managed to persist. This would suggest that Apus had followed its present mode of life through many periods, and the fossil evidence does not contradict this suggestion; for the single Apus found in the Buntsandstein may well have drifted in, together with the numerous remains of landplants (Voltzia, etc.) found in that Triassic terrane. Regarding the character of the Oklahoma deposit, from which our speci-

[1] Weigand, 1913.

[2] See Schuchert, 1897, p. 675.

[3] Ruedemann, 1918.

mens came, Professor Beede writes me under date of December 14, 1921, that it might be brackish water or, possibly, even fresh.

Leaving out the *Apus dubius* Prestwich, described from the Coal Measures of England, which, according to Beecher,[1] "seems to be an abdominal segment or plate of some eurypterid," there is evidence of a still older form, at least closely related to Apus, even in the Lower Cambrian. This is the well-known *Protocaris marshi* Walcott from the Waucoban (Georgian) of Georgia, Vermont. Its similarity to Apus was recognized by Walcott[2] and has since been commented upon by Clarke[3] and Bernard,[4] the latter author even proposing to call the form *Apus marshii*.[5] This Cambrian relative has also been found in but a single example and therefore was hardly a common marine form, as the tribolites collected in the same beds. Therefore, even this might have drifted in from the fresh water.

As to the remaining fossils that by some have been compared with Apodidae, we refer to Pompeckj's excellent summary in the chapter "Crustacea" in the *Handwörterbuch der Naturwissenschaften*.[6] The remarkable crustacean-fauna discovered by Walcott in Burgess-Pass contains both Notostraca (Burgessia and Naraoia) and Anostraca (as Opabinia, Leancholia, Yohoia), but not any forms that are directly referable to Apus, though some may, according to Pompeckj, be ancestral to later apodids, as Naraoia to the later Carboniferous Dipeltis, which behind the parabolic carapace possesses two large thoracic segments or rather shields.[7] The position of certain finds is considered doubtful, as that of a carapace, similar to Apus, described as *Lynceites ornatus* Goldberg from the Carboniferous of Saarbrücken and now currently referred to the Cladocera. There are further to be mentioned the problematic, laterally compressed carapaces of Ribeiria Sharpe and Ribeirella Schubert and Waagen, which occur in the Ordovician and Silurian of Bohemia, Portugal, England, and North America, and which were placed by Schubert and Waagen with the Apodidae

[1] See Schuchert, 1897, p. 675.

[2] 1884, p. 50

[3] 1893, p. 799.

[4] 1894, p. 413.

[5] Schuchert (1897, p. 674), however, points to the subquadrangular shield and frontal emargination as distinguishing characters.

[6] Pompeckj, 1912, p. 789.

[7] Schuchert, *op. cit.*

and considered as possible ancestors of Apus. Pompeckj holds that neither this nor the leptostracan nature of these fossils can be proved. We believe that the two muscle-impressions which Ribeiria shows on the dorsal median-line[1] indicate that in this form the carapace was attached to the body in nearly its entire length along the dorsal line while in Apus it is free from the cervical fold backward, i.e., in its greater portion. This would already indicate a very different organism, even if the deep transversal sulcus in front of the apex of the casts of Ribeiria could in some way be compared with the cervical fold in the carapace of Apus.

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1913. WEIGAND, BRUNO. *Mitteilung über das Auftreten der Limnadia Hermanni Ad. Brgt. bei Strassburg im September* 1912. *Mitt. d. Philomath. Gesellsch. Elsass-Lothr.* Band 4, Heft 5, 20. Jahrg. (1912).

1918. RUEDEMANN, R. "The Paleontology of Arrested Evolution," *New York State Mus. Bull. 196*, p. 107.

[1] *Ribeiria compressa* Whitfield, *Bull. Amer. Mus. Nat. Hist. N.Y.*, Vol. I, No. 8 (1886), Pl. 33, Fig. 3.

Petrological Abstracts and Reviews

Campbell, Robert. "Rocks from Gough Island, South Atlantic," *Trans. Roy. Soc. Edinburgh*, Vol. L (1914), Part II. Pl. 1.

Describes various igneous rocks collected by the Scottish National Antarctic Expedition, 1902–4.

Clapp, Charles H. "Geology of the Igneous Rocks of Essex County, Massachusetts," *U.S. Geol. Surv., Bull. 704* (Washington, 1921). Pp. 132, pls. 18, maps 2.

In this report is given a summary of previous work done in this interesting region of alkalic rocks, and considerable new or unpublished data are added. Two groups of rocks are recognized, an older subalkaline group consisting of granites, granodiorites, quartz-diorites, gabbro-diorites, and gabbros, and a younger alkaline group consisting of alkali-granites, alkali-syenites, and nephelite-syenites, with some diorite, diabase, and gabbro. There are many varieties of dike rocks, quartz-porphyries, paisanites, sölvsbergites, tinguaites, diabases, camptonites, vogesites, kersantites, minettes, fourchites, quartz-keratophyres, etc. The petrographic descriptions are fairly complete, many analyses are given, some of the modes are determined, and the structural relations are described. Of the essexite of Salem Neck, the author says (pp. 124–25): "It is not a differentiate of the alkaline or nephelite syenite but is a contact-metamorphosed gabbro or gabbro-diorite of the Salem type or in some places a metamorphosed olivine-bearing diabase. The schistose varieties and the more siliceous varieties of essexite, such as those containing microperthite, considerable nephelite, and large fawn-colored augites, are true hybrid rocks."

Cockfield, W. E. "Sixtymile and Ladue Rivers Area, Yukon," *Canadian Geol. Surv.*, 1921. Pp. 60, pls. 6.

This report, largely stratigraphic and economic, contains general descriptions of various schists, amphibolites, granite-gneisses, pegmatites, andesites, diabases, rhyolites and granite-porphyries, and various ash beds and sediments.

COLLINS, W. H. "The Age of the Killarney Granite," *Canadian Geol. Surv., Museum Bull. 22* (1916). Pp. 12, pl. 1, map 1.

The Huronian formations along the coast of Lake Huron have been greatly folded and faulted, and intruded by granite batholiths. Both disturbance and granite invasion were completed long before Ordovician time.

COLONY, R. J. "Petrographic Study of Portland Cement," *School of Mines Quart.*, Vol. XXXVI (1914), pp. 1–21. Figs. 14, bibliog. 14 items.

Gives petrographic criteria by which the fitness of cement and concrete may be judged.

DALY, REGINALD A. "Petrography of the Pacific Islands," *Bull. Geol. Soc. Amer.*, Vol. XXVII (1916), pp. 325–44. Bibliog. 58 items.

Concludes that underneath the Pacific Ocean the only primary magma is basalte, that pyroxene andesite and picrite are direct differentiates from it, and that the alkaline rocks may possibly be due to the solution of small proportions of limestone. There is a nine-page alphabetic list of the various islands with the different rock types occurring on each, and a list giving the number of islands from which the various rocks have been reported.

DALY, REGINALD A. "The Geology of Pigeon Point, Minnesota," *Amer. Jour. Sci.*, Vol. XLIII (1917), pp. 423–48. Figs. 5.

Believes that the "red rock" originated through both assimilation and differentiation rather than through the differentiation of a wholly primary magma, but says a final decision concerning its origin must for the present be delayed.

DALY, REGINALD A. "Metamorphism and Its Phases," *Bull. Geol. Soc. Amer.*, Vol. XXVIII (1917), pp. 375–418.

Proposes to classify metamorphic processes as follows:

A. Regional metamorphism.
   1. Static metamorphism.
      a) Stato-hydral or hydrometamorphism (low temperature).
      b) Stato-thermal or load metamorphism (high temperature).

2. Dynamic metamorphism.
   a) Dynamo-hydral or slaty (?) metamorphism (low temperature).
   b) Dynamo-thermal or friction (?) metamorphism (high temperature)
3. Dynamo-static metamorphism.

B. Local metamorphism.
1. Contact metamorphism.
2. Load-contact metamorphism.

DRESSER, JOHN A. "Granitic Segregations in the Serpentine Series of Quebec," *Trans. Roy. Soc. Canada*, Vol. XIV (1921), pp. 7–13.

Granitic dikes are limited to the peridotite-serpentine area of this region, and are believed to be local fillings of contraction cracks in the cooling peridotite by part of the still liquid acidic magmatic residues. Larger irregular masses are believed to be residual segregations from the magma of the peridotite and to have been formed *in situ* by differentiation.

DU TOIT, ALEX. L. "The Karoo Dolerites of South Africa: a Study in Hypabyssal Injection," *Trans. Geol. Soc. South Africa*, Vol. XXIII (1920), pp. 1–42. Figs. 5.

The uneroded remnants of strata invaded by these South African "dolerites" (British usage) cover fully 220,000 square miles, and fully half as much more has been removed. The rocks are composed of labradorite and augite, with or without olivine, and are of ophitic texture. They are almost exclusively confined to beds of the Karoo system, and date from the Rhaetic or Lias, Middle Jurassic at latest. The intrusions form intersecting dikes and a series of sheets, one above the other. The latter are practically horizontal and vary in thickness from 100 to 3000 feet, although in some cases still thicker sheets are found. Thus the curved sheets of the Queenstown district attain a thickness of fully 1,500 feet and cover some 40 square miles, and the Ingeli mass is over 3,000 feet in thickness. Metamorphic action is practically confined to baking of the sandstones and shales into quartzite and hornstone. With the exception of a few isolated and small-scale cases, no signs of assimilation of the strata by the invading magma were found. The sheets, with the exception of decrease in size of grain at the margins, are generally uniform in texture. In a few localities, enstatite partially or

wholly replaces augite, and the rock has a gabbroidal texture; in others there are more acid phases, and the rock passes through quartz-dolerites and diorites to granophyres and granites. All such departures are thought to be due to post-injection into the cooling body, or pre-injection into the intercrustal reservoir. The intrusive sills belong to one period of injection, and all phases were completed within a relatively short time. Disbelieving that the intrusion could have taken place at one time, owing to the fact that the slabs of sediment maintained their orientation, Du Toit thinks that they were injected progressively from the summit downward to the base, a mode of injection which he describes as decensional *lit-par-lit* stoping.

EGGLESTON, J. W. "Eruptive Rocks at Cuttingsville, Vermont," *Amer. Jour. Sci.*, Vol. XLV (1918), pp. 377–410. Figs. 5.

The eruptive body at Cuttingsville, Vermont, is thought to be a composite stock, all of the rocks presumably coming from a single magma. Essexite was the earliest intrusion, and nordmarkite the last. Hornblende-biotite-syenite, pulaskite, foyaite, and sodalite-nephelite-syenite probably came between these two in about the order given. The order of intrusion of the dikes is likewise from basic to acid. Essexite-porphyries were earliest, some of them perhaps apophyses from the essexite body. Aplite came after nordmarkite, and between these there were syenite-porphyries and pulaskite-porphyries. There are also dikes of tinguaite and of camptonite. The descriptions are not always clear. Thus under essexite it is said that the plagioclase ranges from Ab_7An_3 to Ab_3An_7, but it is not stated whether this is zonal, whether two different plagioclases occur in the same section (!), or whether the plagioclase differs in different parts of the area. A system of classification unknown to the reviewer is used, for the statement is made that "the abundant plagioclase allies it [the so-called syenite] to monzonite, but the ratio of dark silicates to feldspar warrants the designation of the rock as a hornblende-biotite-syenite." When it is stated that the "pyroxene is next to the feldspars in abundance," one imagines that it must be present in approximately the same quantity, yet the amount of feldspar is given as 90 per cent, sodalite as 3 per cent, and nephelite 3 per cent, leaving 4 per cent to be divided among pyroxene, biotite, apatite, magnetite, titanite, and possibly pyrite. The norm shows 2.35 per cent of corundum, but no feldspathoid. With five good rock analyses and an analysis of the hornblende, more carefully modal percentages would have been very instructive.

EITEL, W. "Über das Vorkommen von Zinkblende im Basalt des Bühls bei Cassel," *Centralbl. f. Min.*, etc., 1920, pp. 273–85. Figs. 6.

Describes the occurrence of zinc blende in basalt. At an unknown depth, the erupting basalt broke through dikes of blende with a little pyrite and much quartz. Included fragments of the dike rock were assimilated and recrystallized.

EITEL, W. "Bemerkungen zu einer Untersuchung von Lewkonja über die von Hornstein im Basalt des Bühls bei Kassel gefundenen Eisenknollen," *Senckenbergiana*, Vol. II (1920), pp. 130–33. Figs. 2.

Native iron, from the basalt of the Bühl, near Cassel, is described.

EITEL, W. "Bemerkungen zu chemischen Untersuchungen des Herrn F. Flade über das Eisenvorkommen im Bühl bei Cassel," *Senckenbergiana*, Vol. II (1920), pp. 158–63.

Gives an early (1909?) chemical analysis of the Bühl native iron.

EITEL, W. "Studien über die Genesis der Einschlüsse des Bühlbasaltes," *Abhandl. d. Senckenbergischen Naturforsch. Gesellsch.*, Vol. XXXVII (1920), pp. 139–76. Figs. 29.

Among the separate studies in this paper are the following: On pseudomorphs of pyrrhotite after pyrite in the Bühl basalt; on the origin of the magnetite inclusions in the Bühl basalt; a comparative study of the native iron from Ovifak and Bühl; on the genetic relationship of the native iron to the inclusions of pyrrhotite and magnetite; the relationship between the strata penetrated by the Bühl basalt and the inclusions in the latter; experimental studies on the formation of pyrrhotite from pyrite at high temperatures; on the occurrence of a sillimanite-graphite rock with pseudomorphs of spinel, rutile, and enstatite after garnet as an inclusion in the Bühl basalt; and the gas reactions in the Bühl basalt and their rôle in the origin of the native iron.

ESKOLA, PENTTI. "The Mineral Facies of Rocks," *Norsk, geol. tidskrift*, Vol. VI (1920), pp. 143–94.

Metamorphic rocks, by recrystallization, may arrive at a state of chemical equilibrium. The term "metamorphic facies" is here used to designate a group of rocks characterized by a definite set of minerals

which were at perfect equilibrium with each other under the conditions of their formation. Igneous rocks, likewise, may reach a state of equilibrium, and igneous and metamorphic facies may be spoken of together as mineral facies. Mineral facies, therefore, comprise all rocks which have originated under conditions of temperature and pressure so similar that from a definite chemical composition there results the same set of minerals, regardless whether formed by primary crystallization or by metamorphism.

ESKOLA, PENTTI. "On the Igneous Rocks of Sviatoy Noss in Transbaikalia," *Överskit av Finska Vetensk.-Soc. Förhand.*, Vol. LXIII (1920–21), pp. 1–99. Figs. 9.

This is an abstract from the reports of the Moscowian expedition to Transbaikalia in search of radium in 1914. Two great complexes of rock were found, a granite-granodiorite mass and the injected crystalline schists. The first mass is here and there intersected by lamprophyric, aplitic, and pegmatitic dikes, and there are larger aplitic masses. As the boundary between the granite and the migmatite is approached, the aplitic portions increase, until near the border there is an almost uninterrupted zone of light gray, aplitic granite. Still farther west the inclusions of crystalline schist become more numerous and the rock grades into migmatite with only occasional veins of granite. Before the intrusion of the granite, the crystalline schists were invaded by diorites and gabbros which are now metamorphosed and foliated, and cut by the later aplites and pegmatites.

The main igneous complex is called granodiorite, following Iddings, although the alkali feldspar and lime soda feldspar are in nearly equal amounts and therefore, as Eskola clearly recognizes, more rationally quartz-monzonite. The complete mode is not given. The aplitic border has a calculated mode which probably closely approximates the true composition. According to the reviewer's classification it is 227′ (new form), consequently a granodiorite-aplite, the plagioclase being almost twice as abundant as the microcline. Two types of "sviatonossite" are described, one aplitic, but otherwise the two are of practically the same composition. They contain 25–31 per cent potash feldspar, 45–48 per cent oligoclase to andesine, 9–10 per cent andradite, and 8–17 per cent aegirite-augite and accessories. The author says they are andradite-syenites, but from the proportions of potash feldspar and plagioclase the reviewer would call them andradite-syenodiorites, or, if monzonites are considered in the classification, andradite-monzonites. They fall just over the line in Family 11″ (2211″), very near 11′.

REVIEWS

The Copper Deposits of Ray and Miami, Arizona. By FREDERICK LESLIE RANSOME. U.S. Geological Survey, Professional Paper 115. Washington: Government Printing Office, 1919. Pp. 186, pl. 54, index.

The region described is about 70 miles southeast of the center of Arizona, in the mountainous district separating the plateaus of northeastern Arizona from the desert plains of the south. The Ray district lies in Pinal County; Miami is 18 miles north-northeast of Ray in Gila County, and 4 miles west of Globe, the geology of which was described by Ransome in *Professional Paper 12*.

A brief description of the earlier mining operations is followed by a bibliography and commentary. The stratigraphy of the region is then considered. The area is crossed by four ranges of hills and mountains, trending roughly northwest and southeast and separated by broad valleys which are partly structural in origin. The rock sequence comprises limestone and clastic sediments of pre-Cambrian, Cambrian, Devonian, and Carboniferous age, followed by intrusives of Mesozoic and Tertiary time, above which lie Tertiary and Quaternary clastics and lava flows. The succession does not differ markedly from that of the Globe district as presented in the work already referred to. The pre-Cambrian rocks are partly sedimentary, partly meta-igneous, as shown by chemical analysis and petrographic study. New formations are distinguished in the Cambrian, thanks to the better exposures in this area. These and the succeeding rocks are described in chronologic order, without separating the igneous rocks, as is the common custom.

Notable igneous intrusions occurred during Mesozoic times, the magmas ranging from basaltic to granitic. Andesitic extrusions of Cretaceous age are noted; no definite progressive differentiation is observed. The early Tertiary, too, was marked by acid and intermediate extrusions, and these were succeeded in turn by the deposition of conglomerates, sandstones, and flows of which the Gila conglomerate (provisionally assigned to the Pleistocene) is especially noteworthy; this formation is thought to be of alluvial origin and has a thickness of 2,500 feet; it offers attractive problems to the student of sedimentation.

A table shows the correlations of the rocks with the Grand Canyon section.

Structurally the region forms a part of the Great Basin Province. The faulting, which is especially prominent in the southerly ranges, is of the mosaic type, the displacement being normal for the most part, though thrusts are known, possibly attributable to the crowding incidental to block faulting. Excellent plates illustrate the topographic effects of homoclinal structure. Folding is, on the whole, negligible, though some of the field relations might be explained on this basis. The block faulting is supposed to be an expression of larger movements of the same sort, and the great valleys between the four ranges, the Globe Hills, the Pina-Mescal Mountains, the Dripping Springs Range, and the Tortillas, are all thought to have a tectonic rather than a purely erosive origin.

The ores of Ray and Miami are of the familiar disseminated type, the ore bodies being large and of tabular form. The metallization did not follow regular or systematic zones of fissuring, but networks of small fractures resulting from widespread disturbance of the rocks. The ore bodies are undulating, flat-lying masses of irregular horizontal outline and variable thickness, and they mostly lack sharp boundaries. The ore body constituting the east part of the Miami-Inspiration zone has a total length of 5,500 feet and a maximum width of 1,600 feet. The average thickness of the Ray ore body is estimated at 120 feet and its maximum at 400 feet. The average thickness of the Miami ore zone has not been estimated, but is somewhat greater.

The shapes of the ore bodies have been determined largely by extensive drilling, and graphs in which the copper assays of drill-hole samples from various depths are plotted, are used effectively to bring out the demarkation between the three principal zones, (1) the leached zone nearest the surface, (2) the zone of sulphide enrichment, and (3) the unenriched protore.

By far the greater part of the ore in both districts is mineralized Pinal schist; a relatively small amount is mineralized granite porphyry or quartz monzonite porphyry. Drilling at Ray has disclosed important bodies of undeveloped ore in diabase.

The principal metallic minerals of the protore are pyrite and chalcopyrite. The protore at Miami appears richer than that at Ray, the average of 126 assays under the main Miami ore body being 1.18 per cent. At Ray the copper tenor of the protore usually lies between 0.3 and 0.7 per cent.

The principal metallic mineral of the sulphide ore is chalcocite, and the average tenor of the ore thus far mined by the Ray Consolidated, 1.7 per cent copper. The average tenor of the ore sent to the Inspiration mill in 1916 was about 1.55 per cent copper.

The oxidized material is of two kinds. The first carries chrysocolla, azurite, and malachite, and is in part rich enough to ship to the smelter. Such material is relatively little iron-stained and is formed by the encroachment of oxidation in nearly pure chalcocite ore. The second type of oxidized material is leached of copper; it is *not* stained blue or green, but is mostly reddish from iron oxide. It is formed by the oxidation of material carrying considerable pyrite. No criteria were developed for recognizing capping over rich ore bodies beyond the observation that very red capping is likely to overlie protore or thin, highly pyritic ore. Assays of this sort of capping show from a trace to 0.2 per cent copper. The average thickness of the oxidized zone at Ray is 250 feet (range 45 to 600 feet).

The lower limit of oxidation and the position of the ground-water level at the time mining began were far from coincident, the divergence being particularly striking at Miami. Drill holes show that enriched ore lies partly above and partly below that water level. This suggests that enrichment was related, in important measure, to an earlier topography. This conclusion is supported by evidence which shows that much faulting has occurred subsequent to enrichment bringing oxidized and leached material in some places in lateral contact with rich ore on the same level. Rounded fragments of crushed chalcocite ore and fragments of oxidized material are found in the gouges of a number of these faults. The Pleistocene (?) Gila conglomerate appears to have been deposited subsequent to most of the enrichment, for the ores lie deepest in fault blocks capped by this conglomerate.

The deposition of the protores is attributed to thermal solutions coming from deep-lying portions of the granite-porphyry magmas, probably in early Tertiary times.

E. S. B. AND C. H. B.

Gypsum Deposits of the United States. By R. W. STONE. U.S. Geological Survey, Bull. No. 697, 1920.

This bulletin was prepared to take the place of Bulletin No. 223 published in 1904, on the same subject. Since that time (to 1918) the production of gypsum has increased more than 300 per cent. In 1918 the production was valued at $11,000,000.

Gypsum deposits are classified according to origin, mode of occurrence, relation to the earth's surface, etc.

According to mode of occurrence there are the following classes: (1) Interbedded deposits alternating with shales, limestones, and sandstones, laid down in seas or lakes. (2) Efflorescent deposits due to evaporation of water which has come to the earth's surface through gypsum deposits. The result is gypsite, a finely crystalline form of gypsum. (3) Periodic lake deposits due to deposition of gypsum from the waters of intermittent lakes. These are granular and crystalline, and vary much in size. (4) Gypsum veins due to re-working of deposits of the bedded type by ground water, and redeposition in veins. The deposits are crystalline, occurring as satinspar or selenite. (5) Gypsum dunes due to disintegration of massive gypsum or efflorescent deposits, and their transport by the wind. (6) Isoltate crystals and flakes due to formation of sulphuric acid from pyrite and the reaction of the latter on limestone.

According to origin the deposits are classified as: (1) surface-water deposits; (2) ground-water deposits.

In age gypsum deposits vary from Silurian to Quaternary. In 1918 gypsum was produced in eighteen states and in Alaska. New York was the largest producer, Iowa second, and Michigan third.

In New York gypsum has been mined more than one hundred years, during which time it is estimated that about ten million tons have been produced. The deposits are in the Salina (Silurian) formation. The gypsum is in a series of lenses and was deposited by evaporation from an inland sea. The future of the industry in this region is difficult to predict, since the gypsum beds run under younger rocks to the south and the distance they can be profitably mined is uncertain.

In Iowa there are two areas of gypsum, the area around Fort Dodge being the more important. Here the gypsum occurs in bedded deposits which overlie the Mississippian and Pennsylvanian unconformably. They are thought possibly to be Permian. These beds have been worked since 1872. At Centerville gypsum was discovered a few years ago at a depth of 500 feet, but is not yet developed. At this place the gypsum is in limestone of Mississippian age.

In Michigan the deposits are in the Michigan formation of the Mississippian system, and in the Bass Islands formation, and Salina formation of the Silurian. The gypsum is of the massive rock variety, and constitutes lenses in shale and limestone. The deposits are almost inexhaustible. The chief development is in the central part of the southern peninsula at Grand Rapids, and north of Saginaw.

In the west production of gypsum is not very great, but a number of states, especially Oklahoma, Wyoming, Utah, Nevada, California, and New Mex'co have large reserves. The Wyoming deposits are found in the Embar (Permian), Chugwater (Permian or Triassic), and Spearfish (Triassic) formations. The deposits are in the Red Beds.

In California the most promising deposits are south of San Francisco Bay, associated with Tertiary and Pleistocene formations. The most valuable are of the gypsite variety. Many of them lie on the side of knobs or ridges. The deposits are due to the ground water being drawn to the surface and evaporating, leaving behind its load of gypsum acquired from the underlying rocks. There are two other forms of deposits in the California districts, intermittent lake deposits and interbedded deposits.

In New Mexico there are large deposits of gypsum which have been developed but little. They occur as bedded deposits in the Manzana group of the Pennsylvanian and in the Wingate Sandstone of the Jurassic. In the top of the latter there is a bed 100 feet thick. Gypsum also occurs as surface crusts due to evaporation at the surface, and as dunes, the material being derived from such crusts. The dunes are in the Tulurosa Desert and cover an area of 270 square miles. The gypsum from the dunes is used to a slight extent.

F. P. S.

Geology of Webster County and a Portion of Mingo District, Randolph County, South of Valley Fork of Elk River. By DAVID B. BEGER. West Virginia Geological Survey, 1920. Pp. 682, pls. 35, figs. 24, maps 2.

Webster County lies in the Cumberland Plateau, the westernmost division of the Appalachian province. The topography is characterized by deep valleys cut into an old peneplain, the relief varying from 500 to 1,000 feet. The structure is a gently southeastward dipping monocline with some minor folds. The stratigraphic range includes beds of the Upper Mississippian and Pennsylvanian. The Allegheny, and the Kanawha and New River groups of the Pottsville, form the greater part of the surface outcrops, the Monongahela having been entirely stripped off and the Conemaugh mostly. Mississippian formations, represented by the Mauch Chunk shales, of continental origin, and the Green Brier limestone, outcrop only in some of the deeper valleys of the county and in the included portion of Randolph County. The latter is remarkable for its profusion of marine forms. Devonian beds are known only from deep-well records.

The area under consideration lies to the southeast of the main proved oil and gas belt of the state. Six deep tests showed no oil and but four of them gas. It is to be noted, however, that not one of the six was drilled on a favorable structure.

Webster County, although possessing an immense amount of good coal, has but little commercial mining and no coke production. There are nineteen coal beds that appear to be workable commercially. The author estimates that the total recoverable tonnage present is about 5,144,000,000 tons.

Other minor resources include the following: (1) unutilized water power; (2) iron ore (possibly); (3) clay, not extensively utilized; (4) limestone the Hinton member of the Mauch Chunk and the Green Brier limestone; and (5) sandstone, suitable for building purposes in both the Pennsylvanian and Mauch Chunk.

The portion of the report devoted to paleontology includes some notes by W. Armstrong on invertebrate fossils from the Pottsville series. The following contributions are made:

1. "The Maximum Size of West Virginia Derbyas as Influenced by Sediments." The author concludes that the largest specimens of each species are to be found in the light-colored shales and the purer argillaceous limestones, the smallest in the fine black sediments.

2. "An Example of Shell Regeneration in Derbya crassa." This is an instance of abnormal shell growth repairing a probable break in the shell during the life of the animal.

3. "Notes on the Correlation of Certain Fossiliferous Members of the Pottsville Series." A discussion of the present uncertain status of the question is given. Some faunal lists are included.

4. "Fossiliferous Shale Beds in the Rowlesburg Section."

5. "Invertebrate Fossils Collected from the Pottsville Series of Webster County." In general the Pottsville of West Virginia shows three faunal types, a normal marine type, a restricted marine type, and a fresh-water type. Thirty-two species are listed, of which twenty-three are described and a number figured.

A. C. McF.

Bulletin No. 36, Illinois State Geological Survey. Yearbook for 1916, consisting of administrative report, and economic and geologic papers. Pp. 188, figs. 7, pls. 16, tables 33.

The report consists of four papers, the first of which is the administrative report of F. W. De Wolf, state geologist, for 1916. In Part II by N. O. Barrett, on the mineral resources of the state in 1916, the

author finds that while agriculture is the leading source of wealth, mineral industries are gradually gaining in importance. In 1916, Illinois ranked behind Pennsylvania and West Virginia only, in the total value of mineral production. It ranks first in the country in the production of fluorspar, sand and gravel, and tripoli, third in brick and tile, and coal, and fourth in petroleum, limestone, and clay products. An extensive bibliography is included.

Part III, "Clay Deposits Near Mountain Glen, Union County, Illinois," by Stuart St. Clair, describes the occurrence of a deposit of clay believed to be superior to the foreign product for the manufacture of graphite crucibles and glass pots. It is a bedded deposit, underlain by sand, and overlain by sand, gravel, and in some places by an iron-cemented conglomerate, the whole being covered by loess to varying depths. The base never has been determined by drilling. The sedimentary origin is evident. The area where it is was part of a great Cretaceous-Tertiary embayment. The existence of this deposit has been known for many years, but its development was delayed until the cutting-off of the importation of German refractory clays by the war. Four clay pits are now being worked.

Part IV, "The Structure of the La Salle Anticline," by Gilbert H. Cady. The La Salle Anticline is an asymmetric fold, extending south from La Salle to the oil fields of Crawford and Lawrence counties. It is bordered on either side by synclinal troughs, that on the east forming the northern part of the Indiana coal basin, and that on the west forming the larger and main portion of the Illinois coal fields. There are numerous minor structures. The stratigraphic section includes beds from the St. Peter sandstone through the Pennsylvanian. Several unconformities are described. These are at the base of the Chester and the Pennsylvanian, between the St. Peter sandstone and Platteville dolomite, between the Lower Magnesian limestone and the St. Peter sandstone, and several within the Pennsylvanian. The author suggests that there may be some possible relation between the anticline and the distribution of the areas of dolomization in the Platteville formation.

Two structural contour maps of the area are given. The key beds used in mapping were the top of the St. Peter sandstone and No. 2 coal of the Pennsylvanian.

A. C. McF.

The White River Badlands. By CLEOPHUS C. O'HARRA. South Dakota School of Mines, Bull. No. 13. Rapid City, 1920.

This is a useful volume on the badlands of South Dakota. It outlines the development of knowledge concerning the region, its geology,

and paleontology. The volume is abundantly illustrated and both the formations and the fossils afford excellent material for this purpose. A full bibliography enhances the value of the volume.

R. D. S.

Mineral Resources of Michigan for 1914 and Prior Years. Prepared under the direction of R. C. ALLEN. With a treatise on Michigan copper deposits by R. E. HORE. Michigan Geological and Biological Survey, Publication No. 19, 1915.

Mineral Resources of Michigan for 1917 and Prior Years. Prepared under the direction of R. C. ALLEN. Michigan Geological and Biological Survey, Publication No. 27, 1918.

These volumes were not received until late in 1920. The noteworthy feature (besides the statistics on the copper and iron industries, as well as on the non-metallic minerals) is the presence in the 1914 number of a 150-page treatise on the Michigan copper deposits, by R. E. Hore. This article serves as an excellent summary of existing knowledge on these deposits, as well as giving the author's ideas on the subject. Hore believes the native copper is essentially a primary replacement deposit from solutions (probably carrying the copper as the chloride) which accompanied and followed the extrusion of the lavas. A feature of the work is the presence of some thirty photomicrographs of polished sectons.

D J. F.

Field Methods in Petroleum Geology. By G. H. COX, C. L. DAKE, and G. A. MUILENBURG. First edition, pp. xiv+305. McGraw-Hill Book Company, Inc., 1921. $4.00.

Petroleum geologists, particularly those who are lacking in field experience, will welcome this book. It treats chiefly of the recognition of structural features favorable for the accumulation of petroleum, and of map-making and the instruments used in making maps. It includes the solution of geologic problems and the making of a geologic report. Problems of a "resident geologist" are not included. Graphic solutions of geologic problems are also omitted. It is assumed that the reader has a knowledge of the fundamental principles of geology and mathematics, including trigonometry.

Chapter I contains a description of the large variety of instruments used by geologists, and Chapter II outlines instrumental methods in

general use. Chapters III and IV include a discussion of the surface features which lead to the identification of strata and structural conditions; the methods of obtaining and recording geologic data; also the actual field procedure from the selection of the field party to the preparation of the final reconnaissance or detailed report.

The statement is made (p. 129) that "the field work of a petroleum geologist is . . . . made up largely of a search for anticlines and terraces, and of mapping such areas." This statement would have been more nearly correct a few years ago.

The book contains a glossary of about four hundred words, such as: Algonkian, Carboniferous, Cenozoic, Contours, Dip Slope, Orientation Rod, Stadia, Sedimentation, Volcanic Ash. There is also an appendix containing tables of natural functions, reductions of stadia observations for rod readings of 100, stadia tables for obtaining differences of elevations, gradienter table (Stebbinger drum) for determining distances, and a number of other tables, including barometric corrections.

A limp leather binding and pocket size make the book convenient for field use.

W. O. G.

Lithologic Subsurface Correlation in the "Bend Series" of North Central Texas. By MARCUS I. GOLDMAN. U.S. Geological Survey, Professional Paper 129 A, 1921, Govt. Printing Office, Washington. Pp. 22, pl. 1, fig. 1.

Since the early work of Hatch, the micro-petrology of sediments remained a rather neglected field to which the physiographer has only turned now and then in the exceptional instances when there was a question whether a certain sand was wind- or water-laid, a field almost wholly ignored by the stratigrapher. Now the subsurface lithologic correlations in oil fields have assumed economic importance, however, interest in the long-neglected subject is revived, and geologists are glad to learn of the establishment by the U.S. Geological Survey of a laboratory devoted to the study of sediments. The paper here reviewed represents an invaluable addition to the technology of petrographic correlation from well logs and well samples.

The problem presented was the correlation of sediments thought to be the equivalents of the Smithwick and Marble Falls beds and of a part of the Strawn formation of Pennsylvanian age, as well as of the Lower Bend Series (Mississippian) in north central Texas. The method employed was much like that outlined by Trager (*Econ. Geol.*, XV, 1920);

the more exact scheme of analysis described by Trager, however, was not resorted to. Depths from the surface are plotted as ordinates in ten-foot units and the composition in percentage of argillaceous, arenaceous, flinty, and calcareous sediments, as determined from the log samples, are the abscissae; the diagram thus constructed is essentially a graphic columnar section. Correlation is based on the relative increase or decrease of one type of sediment, rather than on the absolute percentage composition of the bed in question. A mere glance at the plate given serves best to illustrate the method used. Flinty sediments are taken to be equivalents of calcareous deposits, since the conditions under which they originally formed are similar.

Such ratios established a generalized sequence for the counties of Comanche and Palo Pinto (and probably also Eastland and Stephens, the intervening counties). This sequence follows:

Pennsylvanian	Strawn formation True "Upper Smithwick" shale "Smithwick lime" "Lower Smithwick shale" of the Ranger field	= True Smithwick shale
	"Black lime" of the Ranger field A succession of limestones and sandy limestones, hitherto unnamed	= True Marble Falls limestone
Mississippian	Lower Bend limestone Lower Bend shale	

Unconformity

Ordovician—Ellenburger limestone

The entire Pennsylvanian and Mississippian (including the lower part of the Strawn) has an average thickness of 1,100 feet.

No marked unconformities are reported above that which separates the Ordovician and Mississippian, though eleven disconformities of varying importance, not indicated above, are recognized. Several are intraformational. In the case of the disconformities, glauconite and phosphate nodules in some cases mark the plane of separation. These glauconite grains are coarser and less rounded than those of the thick greensands of other horizons and resemble more closely those of the New Jersey Cretaceous. The occurrence of sulphides at the horizons marking ' akinetic" surfaces of maximum base-leveling is another noteworthy feature.

Many other interesting facts are discussed, and points of considerable theoretical significance are brought forward—such as the source of

the oil in the north central Texas region, the northeastern source of the Bend sediments, and the very great trustworthiness of lithologic correlation in regions where faunas change slowly and sediments accumulate rapidly.

The one disappointment felt by the reviewer was due to the lack of explicitness in dealing with the technology of examinations. For novices a careful outline of the things to be sought for in making lithologic subsurface correlations would be helpful.

C. H. B., Jr.

Report on Mining Operations in the Province of Quebec, 1919. Province of Quebec, Canada, Bureau of Mines, 1920. Pp. 160.

The phenomenal growth in the mineral industries of Quebec is evidenced by the increase in the value of her annual mineral output from two and a half million dollars in 1900 to nearly twenty-one million dollars in 1919.

While metals contribute to some degree to this output, Quebec's most important resources are non-metallic—asbestos and building-materials dominating.

Asbestos is to be credited with over half of the total mineral output by value in 1919, the mines of Quebec constituting the world's principal source of this mineral. The United States is very directly interested in this Canadian industry because about 89 per cent of the output comes to the United States, mainly in an unmanufactured state, and is there fabricated for use in the United States and for shipment abroad. Some 3 per cent of the Canadian output is exported directly to England and the remainder to various other countries of Europe and to Japan.

The magnesite industry of Quebec, which came into prominence with the cutting off of the German and Austrian imports during the war, declined in 1919 to less than half the 1918 tonnage.

E. S. B.

Deposits of Iron Ore near Stanford, Montana. By L. G. Westgate. U.S. Geological Survey, Bull. 715-F, 1920. Pp. 85–92.

This report describes several bodies of low phosphorus-hematite ore in the northern part of the Little Belt Mountains. The deposits are as yet undeveloped. Tonnages at two of the best showings are roughly estimated at one and one and one-third million tons respectively.

The main facts of the occurrence and character of the ore and the associated rocks are as follows:

1. The iron ore occurs in tabular bodies at the contact of the porphyry and the Madison limestone. The ore bodies range in width from 5 to 60 feet, and average about 20 feet.

2. The ore is the result of the replacement of the limestone, as shown by its much more uneven contact surface against the limestone and by the retention here and there in the ore body of the banding of the limestone and of parts of the limestone itself.

3. Where the contact is inclined the hematite is more commonly found where the limestone is the footwall.

4. The ore is a compact gray or reddish-gray hematite. It contains in places enough magnetite to make it react to the magnet. It is not to any large degree limonitic at the surface. At the one point where any considerable depth has been reached (125 feet, on the Snowbird claim) the ore contains a little pyrite and chalcopyrite.

The limestone at the contact with the porphyry is usually altered to a yellowish, finely crystalline marble. No contact silicates were seen except a small amount of wollastonite in the rock taken from the tunnel on the Snowbird claim [pp. 90 and 91].

E. S. B.

Gypsum in 1919. By R. W. STONE. Mineral Resources of the United States, 1919. Part II, pp. 99–113.

The gypsum industry in 1919 showed a slight recovery from the low level of production touched in 1918. The report gives the usual statistical data, the only unusual feature being a discussion by Dr. William Crocker, professor of plant physiology at the University of Chicago, of "Agricultural Gypsum and Its Uses."

Eighty years ago land plaster was one of the most used of fertilizers, and there are indications that it will again come into general use.

There are four main uses of this substance in agriculture: As a source of sulphur for alfalfa, red clover, or other crops of high sulphur requirement, and for combination with ground-rock phosphate as a substitute for acid phosphate; as a preserver of manure; as a soil stimulant; and as an amendment for black alkali [p. 109].

E. S. B.